ACPSEM POSITION PAPER

Recommendations for a technical quality control program for diagnostic X-ray equipment

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Abstract

This position paper was produced by a working party set up by the Radiology Special Interest Group of the ACPSEM in 2001. It is designed to give the consensus view of College members in Australia and New Zealand on the nature and frequency of tests which should be performed on diagnostic x-ray equipment to maintain adequate quality control of imaging performance and radiation safety. Tests on mammographic equipment have been excluded having been covered in a previous ACPSEM position paper (Australas Phys Eng Sci Med, 24(3):107-131, 2001). Detailed descriptions of test procedures are not given but it is intended that a series of workbooks should be produced giving College recommended test methods for each imaging modality. The recommendations are produced here in an easy-to-read, tabular form giving the nature and purpose of each test and the implications of non-compliance with regard to image quality and radiation safety.

Key words diagnostic radiology, quality control, radiation protection

Introduction

In 2001 the Australasian College of Physical Scientists and Engineers in Medicine (ACPSEM) published the position paper "Recommendations for a mammography quality assurance program" in Australasian Physical and Engineering Sciences in Medicine. The present position paper makes recommendations for technical quality control of other diagnostic X-ray imaging modalities. The aim of this paper is to define which tests the ACPSEM believes are necessary to ensure appropriate patient and staff safety as well as adequate image quality.

Risk management in a modern diagnostic radiology facility requires that all x-ray equipment used on patients is safe and operating optimally. The basic tests recommended by the College to ensure optimal equipment performance coupled with radiation safety for patients and staff are defined in Appendix 1.

It should be noted that Appendix 1 does not give detailed descriptions of the Quality Control (QC) test methods. These will be published in a separate series of guidance documents, which are presently in preparation. Since State authorities in Australia and New Zealand have already adopted standards, which vary between themselves and from the recommendations of this document, it is accepted that total uniformity across Australasia is unlikely to be achieved at this stage.

The role of the radiology medical physicist

The radiology medical physicist plays a crucial role in achieving the overall goal of optimising patient dose versus image quality in the use of x-ray equipment for diagnostic purposes. The quality control tests outlined in this document are meant to form part of a wider quality assurance program involving radiologists, medical imaging technologists and radiology medical physicists.

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The quality control tests in appendix 1 need to be carried out by, or under supervision of, a medical physicist who is ACPSEM accredited in radiological physics (referred to in this document as a 'radiology medical physicist'). In addition the radiology medical physicist must be involved in the commissioning of all newly installed equipment prior to clinical use. These initial QC tests serve as a baseline that can then be developed further when the technology advances or clinical practice changes.

Appendix 1 describes the purpose and consequences of non-compliance for both established radiographic techniques and the newer emerging x-ray modalities.

Frequency of testing

Recommended testing frequency for system quality control measurements is given in the following table: -

Category of equipment	Recommended interval between tests
Mammographic, CT and fluoroscopic X-ray apparatus (Fixed or mobile).	6-12 months
General radiographic x-ray apparatus (including dental OPG and cephalometric)	12 months. (Maximum 24 months)
CR/DR image receptors and other image processing systems	12 months
Dental (intra-oral) and DEXA	36 months

The frequency of inspection recommended for the different classes of equipment is seen as a compromise between the potential for injury to individual patients undergoing imaging based procedures, the inherent reliability of different modalities and the cost and inconvenience of testing. The aim is always to ensure optimum clinical performance and compliance with appropriate standards and to maintain a high standard of radiological safety. For these reasons the maximum recommended interval between tests for equipment used in screening programs (such as mammography) and high exposure procedures (such as CT and fluoroscopy) has been set at 12 months.

There is still some controversy regarding the appropriate test frequency for general radiographic x-ray equipment. While the risk of high patient doses posed by its use is comparatively low, experience obtained in existing QC programs shows that the rate of non-compliance with required standards may be relatively high with consequent implications for image quality. It is therefore suggested that, although the recommended test interval for this type of equipment is 12 months, it might reasonably be extended to 24 months where this can be substantiated by existing QC programs. This recommendation may change however, with advances in technology and clinical practice.

In addition to the tests listed in Appendix 1 there may be daily, weekly and monthly QC tests as well as an increase in the testing frequencies to those recommended above. Such testing is seen to be vital, particularly with respect to assessment of the image reception and processing components of both film based and digital receptor systems. Details will be provided in the ACPSEM guidance documents (presently in preparation) for each imaging modality. Whenever major changes to x-ray equipment are undertaken (eg. x-ray tube changes), immediate post-maintenance QC testing may be considered necessary.

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Appendix 1

Tests recommended for each imaging modality

1. Fixed and mobile radiographic units (*including OPG and cephalometric*)

Test	Purpose	Implications of non-compliance
Accuracy of Light Beam Collimation and alignment	To determine the congruency of the X-ray beam with the light beam and evaluate the X-ray beam alignment with the centre of the light beam.	The X-ray field is larger or smaller than necessary or misaligned. Unnecessarily high patient doses or incorrect field coverage requiring repeat exposures may occur.
X-ray beam size and accuracy of the X-ray field with the collimators (Cephalometric equipment and Panoramic Tomographic Equipment)	**Cephalometric equipment** To ensure that the radiation field is aligned with and does not exceed the size of the image receptor. **Panoramic Tomographic Equipment** To ensure that the radiation beam size is not greater than the secondary collimator aperture size and that the beam on the image receptor side of the secondary collimator is fully intercepted by the image receptor.	Unnecessarily high patient dose
Light Beam Illuminance	To ensure that the light beam can be seen clearly against the patient.	Inaccurate field placement necessitating repeat exposures.
Radiation Leakage	To identify and quantify radiation leakage through the tube casing or the face and sides of the light beam collimator.	Unnecessarily high patient or operator dose.
Tube Voltage Accuracy	To assess the accuracy of the voltage applied to the tube with reference to the set voltage.	Poor image quality necessitating repeat exposures.
Timer Accuracy	To assess the accuracy of the actual exposure times with reference to the set times.	Over or under exposed images necessitating repeats.
Radiation Output Linearity	To assess the proportionality between tube output and tube mAs over the full range of tube currents and times.	Unpredictable exposure of image recording device necessitating repeats.
Reproducibility	To determine the reproducibility of radiation output, tube voltage and exposure time.	A random variation in image quality necessitating repeats.
Beam Quality. (Half Value Layer)	To assess beam quality by measuring the Half Value Layer (HVL) at given tube voltages.	Poor beam quality giving unacceptably high patient dose.
Automatic Exposure Controls	To ensure that the automatic exposure control is producing film densities (or equivalent exposure indicators for digital receptors) within acceptable limits as the tube voltage and patient thickness vary.	Production of incorrectly exposed images necessitating repeats

2. Fixed and mobile fluoroscopic units

Test	Purpose	Implications of non-compliance
Fluoroscopic Collimation	To ensure that the dimensions of the fluoroscopic X-ray beam are restricted to the image receptor for all fluoroscopic field sizes and focus to image receptor distances (FID) and that the automatic collimation adjustment with change in FID is operational.	Unnecessary irradiation of patient tissues outside the field of view giving increased patient and operator doses.
Radiographic Collimation	To ensure that the radiation field size does not exceed the image field size for all possible radiographic image formats.	Unnecessary irradiation of patient tissues outside the field of view giving increased patient and operator doses or unduly small image sizes, which may necessitate repeat images.
Fluoroscopic Tube voltage accuracy	To assess the accuracy of the tube voltage applied during fluoroscopy with reference to the set voltage.	Poor quality fluoroscopic images leading to prolonged screening times.
Radiographic Tube voltage accuracy	To assess the accuracy of the voltage applied during radiography with the fluoroscopic tube with reference to the set voltage.	Poor image quality necessitating repeat exposures.
Radiographic Timer accuracy	To assess the accuracy of the times of radiographic exposure with reference to the set times.	Over or under exposed images necessitating repeats.
Radiographic Output Linearity	To assess the proportionality between tube output and tube mAs over the full range of tube currents and times.	Unpredictable exposure of image recording device necessitating repeats.
Reproducibility	To determine the reproducibility of radiation output, tube voltage and exposure time in radiographic mode.	Random variations in image quality necessitating repeats.
Beam Quality. (Half Value Layer)	To assess beam quality by measuring the Half Value Layer (HVL) at given tube voltages.	Poor beam quality giving unacceptably high patient dose.
Radiation Leakage	To identify and quantify radiation leakage through the tube casing or the face and sides of the light beam collimator.	Unnecessarily high patient or operator dose.
Automatic Exposure Controls	To ensure that the automatic exposure control is producing film densities (or equivalent exposure indicators for digital receptors) within acceptable limits as the tube voltage and patient thickness vary.	Production of incorrectly exposed images necessitating repeats.
Congruency of X-ray Beam and Displayed Image	To ensure that the area of the X-ray field at the image receptor input corresponds to the image area displayed on the television monitor.	Unnecessary irradiation of patient tissues outside the image field of view giving increased patient and operator doses.
Image receptor Input Dose Rate	To measure the dose-rate at the plane of the image receptor.	High patient doses
Image Quality	To ensure that the image quality is of the standard expected from current fluoroscopic systems.	Prolonged fluoroscopic imaging times giving high patient dose - Failure of diagnosis.
Fluoroscopic Timer	To test the function of the fluoroscopic timer.	Long screening times giving high patient doses.
Maximum Skin Input Dose Rate and automatic brightness control (ABC)	To measure the maximum dose rate in air at the skin surface and establish that the ABC is working reliably.	Poor or inconsistent image quality and/or high patient skin doses

3. CT Scanners

Test	Purpose	Implications of non-compliance
CT Number Accuracy	To ensure that the CT number of water is close to zero.	Incorrect identification of tissue types.
Image Noise	To ensure that the noise is not excessive and does not vary excessively over the image area.	Non-visualisation of small, low contrast lesions.
CT Number Uniformity	To ensure that CT numbers do not vary excessively between the central and outer regions of the field of view.	Incorrect identification of tissue types.
Linearity of CT Number	To ensure that the CT number varies linearly with the linear attenuation coefficient of the material scanned.	Incorrect identification of tissue types.
High Contrast Spatial Resolution	To assess the spatial resolution that can be achieved by the CT scanner independently of quantum limitations.	Non-visualisation of small lesions or other fine structures.
Low Contrast Detectability	To determine the ability of the scanner to detect low contrast objects in the presence of quantum noise.	Non-visualisation of small, low contrast lesions, possibly due to insufficient collection of quanta in the scan protocol.
Normalised CT Dose Index ($_nCTDI$) In Air	To measure the absorbed dose in air at the central axis of the scanner normalised per unit mAs. (This can be used in patient dose estimations eg. Using "CTDOSE" or "ImPACT" software)	Inability to estimate patient doses correctly and potential for excessively high radiation doses to patients.
CT Dose Index $(CTDI)_w$	To measure the weighted absorbed dose for a given slice thickness and to establish that the dose index displayed by the scanner is correct.	Excessively high radiation doses to patients.
Image Slice Thickness	To determine the thickness of a single scan slice	Increased partial volume effects leading to possible misdiagnoses. For multislice scanners differences in slice thickness between different detector rows may indicate a misalignment between the X-ray target, collimation system and/or detector arrays.

4. Computed Radiography and Digital Radiography

Test	Purpose	Implications of non-compliance
Dark Noise	To assess the level of electronic noise inherent in the digital receptor	Poor low-contrast detectability and subsequent non-visualisation of pathology.
Exposure Indicator Calibration	To assess the accuracy of the exposure indicator	Inappropriate (too high or low) technique factor selection and/or inappropriate AEC calibration.
System Linearity and Auto Ranging	To assess accuracy of the exposure indicator over a wide range of incident radiation doses and ensure that images are presented at an invariant brightness or density regardless of receptor dose.	Inappropriate (too high or low) technique factor selection and/or inappropriate AEC calibration. Inconsistent (dose dependent) image display.
Uniformity and artefact Analysis	To assess spatial response to radiation of an image receptor and ensure invariance between detectors for multi-detector (eg. CR) systems.	Mimicking of pathology possibly resulting in mis-diagnosis.
Laser beam function and distance accuracy	To assess computed radiography systems for spatial accuracy	Possible mimicking of pathology. Erroneous quantitative evaluations.
Spatial resolution	To assess the spatial resolution that can be achieved independently of quantum limitations	Local or universal loss of image detail possibly resulting in mis-diagnosis, in particular with respect to fine bony structures.
Image noise/low contrast detectability	To determine the ability of the image receptor to detect low contrast objects in the presence of quantum noise.	Non-visualisation of small, low contrast lesions and/or high patient dose.

4. Computed Radiography and Digital Radiography (continued)

Test	Purpose	Implications of non-compliance
Erasure Thoroughness	To assess the system's ability to adequately remove the signal from previous exposures from the detector.	Possible mis-diagnosis related to artefactual "ghost" images from previous detector exposures.
Aliasing/ grid response	To ensure that clinically utilised stationary grids will not produce unacceptable image artefacts.	Clinically unacceptable aliased patterns may impede accurate diagnosis or in extreme cases render the image totally undiagnostic.

5. Image processing and viewing

Test	Purpose	Implications of non-compliance
Film processing – sensitometry and densitometry	To ensure film processing provides optimal and consistent image clarity as measured by the contrast index, speed index, base plus fog at the specifically used developer temperature. Early detection of processor problems with daily processor QC reduces the need for repeat exposures.	Non-optimal image processing results in poor image quality, which can affect diagnosis or necessitate repeat exposures.
Darkroom conditions – light leakage and safe lights	To ensure radiological diagnosis is not adversely affected as a result of poor image quality caused by exposure fogging due to light leakage or the use of inappropriate safe lights.	Fog decreases image contrast at low to mid film densities, those densities most important in diagnostic imaging. Fog will alter the apparent speed of a film, depending on how much fogging of the film has occurred.
Darkroom conditions - cleanliness	To ensure radiological diagnosis is not adversely affected as a result of images with artifacts caused by dust and dirt contamination on the film or screen.	Dust or dirt artifacts affect image quality and most significantly may mimic or mask microcalcifications in mammography.
Cassettes, screens, film and chemicals	Cassettes, screens, films and chemicals should be matched to provide optimal images. Numbered and labelled cassettes should be monitored for damage and screen-film contact assessed. When cassettes are replaced, the speed of all cassettes used for the same type of image should be checked to ensure consistent film densities. All cassettes, used for the same image type, should be replaced at the same time if possible.	Poorly matched screens, film and chemicals can result in larger exposures and poor image quality. Damaged cassettes can leak light and poor screen-film contact will cause image blur. Variations in cassette screen speed will result in images of variable optical density, which will provide non-optimal, inconsistent image quality and may necessitate repeat exposures.
Viewing boxes and viewing conditions	To ensure radiological diagnosis is not adversely affected by unsatisfactory viewing conditions of radiographic images.	Insufficient or non-uniform viewbox illumination and poor room viewing conditions can reduce perceivable diagnostic information. Insufficient viewbox lighting reduces high frequency spatial resolution. Unmasked areas of the viewing box and high ambient room lighting levels reduce low contrast detectability. Reflections on the viewbox from other light sources in the room can obscure parts the image.

6. Bone densitometry (DEXA) scanners

Test	Purpose	Implications of non-compliance
BMD Reproducibility	To ensure that BMD measurements are accurate.	Inaccuracy in patient bone density measurements
Accuracy of laser light positioning	To assess the accuracy of the laser light position indicator	Inaccurate positioning of the scan field with respect to patient anatomy.
Accuracy of scan line and step spacing	To assess the accuracy of the scan line spacing (and step spacing in pencil beam scanners) as displayed on the scan image.	Image distortion. Inaccurate assessment of object sizes, distances and BMD measurements. Unnecessarily high patient dose.

6. Bone densitometry (DEXA) scanners (continued)

Test	Purpose	Implications of non-compliance
Accuracy and reproducibility of indicated scan time	To assess the accuracy and reproducibility of the set scan time	Unnecessarily high patient dose and inaccurate BMD measurements
Free air entrance exposure dose	To assess the exposure dose to air for common scan procedures	Unnecessarily high patient doses
Skin entrance dose	To assess the exposure skin entrance dose common scan procedures	Unnecessarily high patient doses.
X-Ray scatter measurements	To assess the scatter exposure doses at the edge of the scanning table and the technologist's station.	Unnecessarily high doses to staff.

7. Dental intra-oral apparatus

X-ray Beam Size, alignment and focal Spot to Skin Distance (FSD) for equipment not fitted with light beam collimation.	To ensure that the FSD is sufficient to give acceptable skin doses and that the applicator and primary collimator produce appropriate radiation field sizes.	Unnecessarily high patient skin doses
Tube Voltage Accuracy	To assess the accuracy of the voltage applied to the tube with reference to the set voltage	Unnecessarily high patient dose or poor image quality necessitating repeat exposures
Timer Accuracy (May not be possible with programmed exposure buttons)	To assess the accuracy of the times of exposure with reference to the set times	Unnecessarily high patient dose and/or over or under exposed images necessitating repeats
Radiation Output Linearity with Time	To assess the proportionality of tube output to the exposure time over the full range of exposure times.	Over or under exposure necessitating repeats
Reproducibility	To determine the reproducibility of radiation output, tube voltage and exposure time	Random variations in image quality necessitating repeats
Beam Quality. (Half Value Layer	To assess beam quality by measuring the Half Value Layer (HVL)	Poor beam quality giving unacceptably high patient dose
Air Kerma at Skin Surface	To assess the air kerma at the skin surface for a typical adult bite-wing exposure using an intra-oral apparatus.	Unnecessarily high patient dose.