Image quality standards for digital imaging and interventional radiology

Author: A. Schreiner – Karoussou, C. Back

Lead Partner: RPDMHL (Radiation Protection Department, Ministry of Health, Luxembourg)

Other partners: Houghton Institute, St. James's Hospital, Dublin, Ireland
Krankenhaus der Barmherzigen Bruder, Trier, Germany
Complutense University, Madrid, Spain
Regional Medical Physics Department, Newcastle, United Kingdom
Delft University of Technology, Delft, Netherlands
General Hospital Evagelismos, Athens, Greece

Associated Workpackages: 2.2 QA protocol for digital detectors and new imaging devices
2.8 Define self test QA procedure
2.9 Determine QA procedures for software
3.10 Draft proposal for three international standards for dose area product measurements, patient dose records and connectivity between equipment

1. Introduction

During the past decade digital and interventional radiology have undergone significant developments and continue to do so. Radiology departments in Hospitals are being completely digitised at an ever increasing rate.
Fluoroscopically guided interventional procedures are becoming increasingly common as they avoid the need for complicated surgery and lead to the earlier discharge of the patient. These procedures may involve prolonged irradiations and may subject patients and staff to higher levels of risk than would normally prevail. As a consequence there may be the occurrence of deterministic effects in both patients and staff [1,2,3,4].
The EU Directive 97/43 Euratom [5] on radiation protection of patients was issued in June 1997. This Directive lays down the general principles of the radiation protection of individuals undergoing medical examinations with the use of ionising radiation.
Appropriate Quality Assurance (QA) programmes, including Quality Control (QC) measures and patient dose assessments should be implemented, giving special attention to practices such as interventional radiology (IR) among others.
One of the aims of the DIMOND project is to optimise the dose versus image quality relationship through developing image quality criteria, equipment requirements, and also patient and staff dosimetry approaches. Standards concerning the radiation protection of patients and staff in interventional procedures and the measurement of dose in diagnostic radiology exist [6,7,8]. However there is a great need for the production of image quality standards for digital imaging and interventional radiology equipment.
Quality control of digital imaging equipment is still in an early stage of development. The aim of the work carried out in this work package was to produce recommendations for image quality criteria for digital imaging and interventional radiology equipment.

1. Review DIMOND II and new literature

DIMOND II was reviewed by studying the final report for the DIMOND II Concerted Action (CA) and the publications from the proceedings of a workshop in Dublin published in the Radiation protection dosimetry Vol.94 Nos. 1-2 2001 [9,10,11,12,13,14,15,16,].
The conclusions from the review of DIMOND II are summarised in table 1 and table 2. Table 1 shows the parameters which need to be measured in order to evaluate the image quality of interventional radiology, DSA/DF and computed radiography equipment. Table 2 shows the phantoms and test patterns recommended for the evaluation of this image quality.

Table 1

Parameters to be measured for the evaluation of image quality for three different types of equipment according to the review carried out on DIMOND II

Interventional Radiology	DSA/DF	Computed Radiography
Limiting Spatial Resolution	Minimum Detectable Iodine Concentration	Limiting Spatial Resolution
Low Contrast Resolution	Threshold Contrast Detail Diameter	Dynamic Range
Threshold Contrast Detail Diameter	Contrast Uniformity	Low Contrast Resolution
Signal to Noise Ratio	Dynamic Range	Geometric Distortion
Modulation Transfer Function	Mis-registration	
Wiener Spectra	Limiting Spatial Resolution	

Table 2

Phantoms and test patterns recommended for the evaluation of image quality for three different types of equipment according to the review carried out on DIMOND II

Interventional Radiology	DSA/DF	Computed Radiography
Leeds TOR 18FG	IEC standard phantoms	IEC WG27 phantom
Leeds TO 10		SMPTE test pattern
Leeds TO 20		ADC system test
Leeds E1		

The review of new literature showed the publication of a new document by the British Institute of Radiology. This document is a second edition with the title "Assurance of Quality in the Diagnostic Imaging Department" [17]. This document recommends the measurement of Low Contrast Sensitivity and Spatial Resolution for the assessment of image quality for interventional radiology systems and storage phosphor systems.
The American Association of Physicists in Medicine (AAPM) prepared a document on the Acceptance Testing and Quality Control of Photostimulable Phosphor Imaging Systems [18]. This is a draft document but it has a lot of very interesting information on the quality control of digital imaging systems.
King's centre for the assessment of radiological equipment (KCARE) prepared draft protocols for the QA of computed radiography and direct digital radiography systems [19, 20]. These protocols can be downloaded from the KCARE website and are very well prepared.
The manufacturers of computed radiography systems have sometimes their own acceptance testing procedures (ADC system tests) which are worth looking at.

2. Existing national and international standards

The research on national and international standards gave the following results:

Interventional radiology

NEMA XR-11 -1993 Test standard for the determination of limiting resolution of X-ray Image Intensifier Systems.
These systems include optical viewing systems, video system, photofluorographic film recording systems and cine film recording and projection systems.
IEC 61262-7 (1995-09) Medical electrical equipment. Characteristics of electro-optical X-ray image intensifiers. Part 7: Determination of the modulation transfer function (MTF) (IEC 1262-7:1995)
This standard describes a method for determining the modulation transfer function of image intensifiers.
IEC 60601-1-5 Draft image quality and dose standard.
Concerns image quality and dose for X-ray equipment. Describes the measurement of limiting spatial resolution, low contrast detectability and air kerma-patient entrance dose.
NEMA XR-21-2000 Characteristics of and test procedures for a phantom to benchmark fluoroscopic and photographic equipment.
The phantom and test procedures described in this standard test systems under conditions simulating a range of fluoroscopically guided invasive interventional procedures. These tools provide simultaneous objective measurements and phantom entrance dose.
IEC 61223-3-3 (1996-11) Evaluation and routine testing in medical imaging departments – Part 3-1: Acceptance tests – Imaging performance of X-ray equipment for digital subtraction angiography (DSA).
This standard recommends the measurement of dynamic range, low contrast, limiting spatial resolution and artefacts for interventional radiology equipment with DSA.

Computed Radiography

DIN 6868-58 Image quality assurance in diagnostic X-ray departments – Part 58: Acceptance testing of projection radiography systems with digital image receptors (2001).
This is a German standard which describes the parameters which must be measured for the acceptance testing of computed radiography equipment using a specially designed phantom. The parameters to be measured are Homogeneity, Dynamic Range, Contrast Resolution, Limiting Spatial Resolution, Geometric Distortion and Patient Entrance Dose. These parameters are measured with a specially designed phantom produced by Pehamed and Welhöfer.

DIN 6868-13 Image Image quality assurance in diagnostic X-ray departments- Part 13: Constancy testing of projection radiography systems with digital image receptors. This is a German standard which describes the parameters which must be measured for the constancy testing of computed radiography equipment using a specially designed phantom. The parameters to be measured are the same as for the DIN 6868-58 standard.

IEC 62220-1 Medical electrical equipment- characteristics of digital X-ray imaging devices – Part 1: determination of the detective quantum efficiency (DQE). This standard is a draft standard which describes a method for determining the DQE of digital imaging systems.

3. Range of equipment and detector types to be employed

From the literature review it became apparent that there are three well defined categories of radiology systems for which recommendations on quality criteria were to be developed:

- Interventional radiology equipment with image intensifier systems
- Interventional radiology equipment with DSA systems
- Computed radiography systems with
    - Storage phosphor systems
    - Flat panel detectors

4. W.P. 2.2

This workpackage developed a quality control protocol for storage phosphor systems and flat panel detectors. The protocol is based on the DIN standards 6868-58 and 6868-13. The phantom used is the one recommended by the DIN standards, the DIGRAD from Pehamed. A software was developed for the automatic evaluation of the digital image obtained of the phantom. The parameters evaluated are those described in the DIN standards. Several meetings took place with the DIMOND partner responsible for W.P. 2.2 in order to discuss the protocol and the software. In Luxembourg there are already three fully digitised hospitals and two more to follow. For this reason it was possible to obtain images of the phantom on several systems and to evaluate the software. It was found that the software is a very valuable tool to be used for constancy checking. It allows for a relatively quick, non subjective evaluation of the image quality. The software still needs to be finalised in order to be used on any computer in any hospital. This would be a very useful project for future.

5. Recommendations for image quality standards

Interventional radiology systems and DSA systems

Several meetings took place with the DIMOND partner responsible for the workpackage 5.8 in order to discuss the QA for interventional radiology equipment. It was decided to use the work carried out by Dr David Marsh during the DIMOND II CA and presented in his thesis [21] in order to develop recommendations for image quality criteria. From the work carried out for DIMOND II it was agreed by all the CA participants that Threshold Contrast Detail Detectability (TCDD) and Limiting Resolution can be used to assess the subjective 'image quality', whereas signal to noise ratio (SNR), MTF and Wiener spectra represent an objective description of 'image quality', in association with the 'characteristic curve' of the imaging system. Dr Marsh's thesis lays out methods of measurements for each of these quantities. Clearly defined measurement protocols for what are sometimes very complex and difficult measurements are given. A list of recommended measurement equipment is compiled, which include the Leeds TO10 and TO20 (for subtraction systems), the Leeds E1 for MTF measurements using a well defined edge, the Hüttner resolution grating, and measurements are made using 1.5mm Copper in the beam. The conclusion from Dr Marsh's thesis is that it is unnecessary to perform complex physical measurements (SNR, MTF and Wiener Spectra) in order to establish optimum dose /image quality operating points in digital image intensifier X-ray systems.

From the literature review and from Dr Marsh's thesis it is recommended that in order to evaluate the image quality of interventional and DSA systems the following parameters are measured:

- Limiting Spatial Resolution

- Threshold Contrast Detail Detectability
- Low Contrast Resolution

The phantoms recommended in order to carry out the measurements are the following Leeds phantoms:

- TOR 18FG
- TO 10
- TO 20V

It is however also recommended to measure image intensifier entrance kerma and patient entrance dose.

Digital Imaging

From the literature review it is recommended that in order to evaluate the image quality of computed radiography with storage phosphor systems and flat panel detectors the following parameters be measured:

- Homogeneity
- Dynamic Range
- Contrast Resolution
- Threshold Contrast Detail Detectability
- Limiting Spatial Resolution
- Geometric Distortion

It is also recommended to look for artefacts, to measure the patient entrance dose and to note the exposure indicator.

The phantoms recommended are the following:

- Leeds TO 20 threshold contrast test object
- Leeds TOR 18FG test object
- Leeds M1 geometry test object
- Pehamed DIGRAD phantom
- Wellhöfer DIGI-13 phantom

5. Conclusions

The aim of this workpackage was to produce recommendations for quality criteria standards for digital imaging and interventional radiology equipment. The extensive literature review and the review of existing national and international standards showed that a lot of information exists on the QA for interventional radiology equipment. The same cannot be said for digital imaging equipment.

The review showed that for interventional radiology equipment it is recommended to measure Limiting Spatial Resolution, Threshold Contrast Detail Detectability, Low Contrast Resolution, image intensifier entrance kerma and patient entrance dose. There exists a draft IEC Image Quality and Dose standard which proposes a method for measuring a number of these quantities.

For computed radiography with storage phosphor systems and flat panel detectors no international standards exist. The literature review showed that in order to evaluate the image quality of these systems, Homogeneity, Dynamic Range, Contrast Resolution, Threshold Contrast Detail Detectability, Limiting Spatial Resolution and
Geometric Distortion need to be measured. Two German DIN standards propose a method for measuring these parameters. These standards could be a basis for the publication of international standards.

References

1. F. Granel, A. Barband, M. N. Gillet-Terver , S. Reecehert, M. Weber, N. Daundin and J.L. Scmutz, *Chronic radiodermatitis after Interventional Cardiac Catheterisation. Four cases*. Ann. Dermatol. Venereol. 125, 405-407 (1998).
2. G.T. Nahass, and L. Cornelius. *Fluoroscopy Induced Radiodermatitis after Transjugular Portszstemic shunt.* Am. J. gastroenterol. 93, 1546-1549 (1998).
3. M.S. Stone , K.L. Robson and P.E. Le Boit. Subacute radiation Dermatitis from Fluoroscopy during Coronarz Arterz Stenting: Evidence of Cztotoxic Lymphocyte Mediated Apoptosis. J. Am. Acad. 38, 333-336 (1998).
4. E.Vano, L.Arranz, J.M. Sastre, L. Moro, A. Ledo, M.T. Garate and I. Minguez. *Dosimetric and Radiation Protection Considerations based on some cases of Patient Injuries in Interventional Cardiology.* Br. J. Radiol. 71, 510- 516 (1998).
5. European Commission (EC*). Council Directive of 30 June 1997 (97\43 Euratom) on Health Protection of Individuals Against the Dangers of Ionising Radiation in Relation with Medical Exposure* (Luxembourg: EC) Official Journal of the European Communities, No L 180 22 (1997).
6. IEC, International Standard IEC 60601- 2-43, *Particular requirements for the safetz of X-ray equipment for interventional procedures*, Geneva (2000).
7. IEC, International Standard IEC 60580, *Medical Electrical Equipment: Dose area product meters*, Geneva (2000).
8. Food and Drug Administration Code of Federal Regulations Section 1020.32 (21 CFR 1020.32) *Diagnostic X/Ray Equipment Perfomance Standard*.
    A. R.M. Gagne and T. B., *Shope Regulatory Initiatives and Framework in the U.S.A : Interventional Radiology,*Radiation Protection Dosimetry ,Vol.94,Nos 1-2, pp. 13-18, (2001).
9. D. Marsh and J. F. Malone, *Methods and Materials for the measurement of Subjective and Objective measurements of Image Quality.*Radiation Protection Dosimetry ,Vol.94,Nos 1-2, pp37-42, (2001).
10. J. Zoetelief and K. Faulkner *Equipment requirements and specification for digital and interventional radiology.*Radiation Protection Dosimetry ,Vol.94,Nos 1-2, pp. 43-48, (2001)
11. A. Schreiner Karoussou*, The Quality Assurance and Constancy Checking of Fluoroscopy and Fluorography Systems*, Radiation Protection Dosimetry ,Vol.94,Nos 1-2, pp. 49-52 , (2001).
12. J. Zoetelief, *Review of acceptability criteria for X ray systems relevant for digital radiolog,y*.
    Radiation Protection Dosimetry , Vol.94, Nos 1-2, pp. 59-64. (2001).
13. K. Faulkner, *Introduction to Constancy Check protocols in Fluoroscopic systems,* Radiation Protection Dosimetry ,Vol.94,Nos 1-2, pp. 65-68, (2001).

14. J. Kotre and N. W. Marshall, A *Review of Image Quality and Dose issues in Digital Fluorography and Digital Subtraction Angiography, R*adiation Protection Dosimetry ,Vol.94,Nos 1-2, pp. 73-76, (2001).
15. H. Bosmans, A.K. Karton, H.Pauwels, T. Deprez and G.Marshal,*The Assessment of Dose and Image Quality of Storage Phosphor Systems: an overview of the different tasks,* Radiation Protection Dosimetry ,Vol.94,Nos 1-2, pp. 77-82, (2001).
16. S. Balter *A New Tool for the benchmarking cardiovascular fluoroscopes*, Radiation Protection Dosimetry ,Vol.94,Nos 1-2, pp. 161-166, (2001).
17. The Quality Assurance Working Group of the Radiation Protection Committee of The British Institute of Radiology, *Assurance of Quality in the Diagnostic Imaging Department*, 2nd edition, BIR,2001.
18. Draft document: AAPM Task Group # 10, *Acceptance Testing and Quality Control of Photo Stimulable Phosphor Imaging Systems,* October 1997; version 3.1.
19. King's Centre for the Assessment of Radiological Equipment (KCARE), *Protocol for the QA of Computed Radiography Systems, Commissioning and Annual QA Tests*, KCARE CR Protocol (2003).
20. King's Centre for the Assessment of Radiological Equipment (KCARE), *Protocol for the QA of Direct Digital Radiography Systems, Commissioning and Annual QA Tests,* KCARE CR Protocol (2003).
21. D. Marsh and J. F. Malone, *Methods and Materials for the measurement of Subjective and Objective measurements of Image Quality.*Radiation Protection Dosimetry ,Vol.94,Nos 1-2, pp37-42, (2001).