Radiation Protection Dosimetry (2008), Vol. 129, No. 1–3, pp. 237–243
Advance Access publication 1 March 2008
doi:10.1093/rpd/ncn008

INVITED PAPER

QUALITY CONTROL MEASUREMENTS FOR FLUOROSCOPY SYSTEMS IN EIGHT COUNTRIES PARTICIPATING IN THE SENTINEL EU COORDINATION ACTION

J. Zoetelief[1,*], F. W. Schultz[1], S. Kottou[2], L. Gray[3], U. O'Connor[3], D. Salat[4], K. Kepler[5], P. Kaplanis[6], J. Jankowski[7], A. Schreiner[8], and J. Vassileva[9]
[1]Faculty of Applied Sciences, Delft University of Technology, Mekelweg 15, 2629 JB Delft, The Netherlands
[2]Department of Medical Physics, Medical School, University of Athens, Athens, Greece
[3]Department of Medical Physics and Bioengineering, St James's Hospital, Garden Hill House, Dublin 8, Ireland
[4]Medicontrol, Stanicna 24, 91105 Trencin, Slovakia
[5]Training Centre of Medical Physics and Biomedical Engineering, University of Tartu, 4 Tähe Street, 51010 Tartu, Estonia
[6]Department of Medical Physics, Nicosia General Hospital, 1700 Nicosia, Cyprus
[7]Radiation Protection Department, Nofer Institute of Occupational Medicine, St Teresa 8, Lodz 90-950, Poland
[8]Division de la Radioprotection, Villa Louvigny, L-2120 Allee Marconi, Luxembourg
[9]National Centre for Radiobiology and Radiation Protection, Laboratory for Quality Control in Radiology, 132 Kliment Ohridsky Blvd, 1756 Sofia, Bulgaria

Quality control (QC) is becoming increasingly important in relation to the introduction of digital medical imaging systems using X rays. It was, therefore, decided to organise and perform a trial on image quality and physical measurements. The SENTINEL toolkit for QC measurements of fluoroscopy systems containing equipment and instructions for their use in the assessment of dose and image quality circulated among participants in the trial. The participants reported on their results. In the present contribution, the impact of the trial on the selected protocols is presented. The Medical Physics and Bioengineering protocol appeared to be useful for QC, and also for digital systems. The protocol needs an additional section, or an addition to each section, to state compliance with the requirements. The circular cross-sections of the Leeds test objects need adaptation for rectangular flat panel detector (FPD) systems. Only one participant was able to perform the monitor test using MoniQA. This is due to the fact that assistance is required from the suppliers of the X-ray systems. This problem needs to be solved to apply MoniQA in practice.

INTRODUCTION

Quality control (QC) is becoming increasingly important in relation to the introduction of digital medical imaging systems using X rays. One of the reasons is that overexposed detectors, which provided a natural dose limitation for conventional image receptor systems are no longer observed in digital systems. In SENTINEL work package (WP) 1 on functional performance and standards, it was decided to organise and perform a trial on image quality and physical measurements.

A questionnaire on inventory of equipment and equipment standards was prepared and distributed among prospective participants to collect information on equipment available for measurements in the trial, equipment available for a toolkit to be used during the trial and protocols available for the measurements. Eight participants responded to the questionnaire. Equipment for the toolkit was made available by three participants.

The SENTINEL toolkit containing equipment and instructions for QC measurements circulated among participants in the trial performed in the period of August–October 2006. The participants reported on their results in the period of August 2006–February 2007. In the present contribution, the impact of the trial on the selected protocols is presented.

MATERIALS AND METHODS

The questionnaire on inventory of equipment and equipment standards was distributed on 1 June 2005 among 10 SENTINEL partners who expressed to have an interest in WP1. SENTINEL partners 2, 8, 11, 12, 13, 14, 15 and 19 responded to the questionnaire. They provided equipment specifications of 15 units available for (digital) fluoroscopy. They also expressed interest in participating in the trial on image quality and physical measurements.

*Corresponding author: j.zoetelief@tudelft.nl

During the SENTINEL meeting in Lodz (October 2005), it was proposed that the most practical solution would be to use the protocols of the Department of Medical Physics and Bioengineering (MPBE) in Dublin as starting point for QC of conventional X-ray systems since they are complete for that purpose and are based on IPEM 77[1] and IPEM 32[2]. Protocols that appeared during 2005 or more recently were not available at the time. At the SENTINEL meeting in Trier, Germany (February 2006), it was agreed to use the MPBE protocol for QC of fluoroscopy systems. This protocol includes measurements on X-ray tube and generator, automatic exposure control, patient dose and image quality.

In addition, monitors were to be checked using a software tool, MoniQA[3], made available by the University of Leuven, Belgium.

The SENTINEL toolkit (Table 1) containing equipment and instructions for their use circulated among seven participants (Table 2) in the period of August–October 2006. The Leeds test objects were provided by partner 2 (Department of MPBE, Dublin, Ireland), the instruments by SENTINEL partner 8 (Division de la Radioprotection, Luxembourg) and the shielding materials and the protective case by partner 10 (Delft University of Technology, Delft, the Netherlands). Owing to problems related to customs (Bulgaria was not yet a full EU member state in 2006), the measurements in Bulgaria were made with local equipment, using the protocol and the monitor test tool MoniQA.

The participants and the fluoroscopy systems for which the trial was performed are shown in Table 2. The results of the monitor tests were quite disappointing (Table 2), i.e. only one participant was able to perform the tests with MoniQA. It appeared that it is not simple to install the software since assistance is required from the suppliers of the monitors. The suppliers are apparently hesitant to install other software than their own. The participants had the toolkit available for measurements for 1 week.

RESULTS AND DISCUSSION

Various tests were performed by the participants according to the protocol MPBE QC of fluoroscopy system using the equipment and instructions provided with the toolkit. In this section, it is indicated whether the participants provided descriptions and performed tests. In addition, problems experienced by the participants were noted and/or improvements suggested for (sections) of the protocol.

System details

The section in the protocol on system details was completed to various extents by the participants (Table 3). It is proposed to add options 'under couch tube' and 'flat panel detector' to the table in the protocol. Test equipment (instruments) could be presented in the table given in the protocol as options. This latter provision would make completion easier. Maybe participants presumed that the equipment was known since, generally, the toolkit was used.

Tube and generator performance

How far tube and generator measurements were performed is shown in Table 4. It appeared that various QC measurements concerning tube and generator performance are not easily performed for modern equipment. Since tube and generator performance of modern equipment is usually much better than for older equipment, the protocol could be restricted to 'tube output varying potential' and to 'tube output consistency'. The specification of performance

Table 1. Contents of the SENTINEL toolkit for the trial on QC of fluoroscopy units.

Leeds test objects (S/N 28)
0.5 mm copper filtration (15 × 15 cm)
1 mm copper filtration (15 × 15 cm)
1.5 mm copper filtration (15 × 15 cm)
SW4 grey scale test object
FSG4 matrix/field size test object
Hüttner line pair resolution phantom type 18
SSM4 710 μm woven mesh test object
LCD4 noise test object
TCD4 contrast detail test object
VS4 edge test object
Manual
BNC cable + three connectors
Instruments
Unfors Instruments kVp meter, Type 9001, S/N 91728
Unfors Instruments Mult-O-Meter, Type 731L, S/N 125534
+ Prova 15 AC/DC mA Current Probe (clamp), no. 02200480
+ Pen detector holder
Manual for Mult-O-Meter + Addendum
Manual for Test-O-Meter
Radcal Corporation Radiation Monitor Controller, Model 2026C, S/N 260276
Radcal Corporation Electrometer/Ion Chamber, Model 20 × 6–60, S/N 21860
Serial connector cable
Certificate of calibration (John Perry Radiation Metrology Laboratory, job no. 7168)
Instructions for use
Shielding material
4 mm lead filtration (13 × 10 cm); weight 600 g
Documents/Quality assurance protocols
MPBE QC, Fluoroscopy System
MPBE quality assurance, general X-ray system (for background information only)
Reference to website to download MoniQA software

Table 2. Overview of the measurements made by the partners using the Toolkit.

Partner	Fluoroscopy protocol	Imaging system	Monitor tests
2, Ireland	Siemens Multistart	II + CCD	No
	Philips Easy Diagnost	II + TV	No
8, Luxembourg	Siemens Axiom Artis	Flat panel	No
11, Greece	Philips Integris V3000	II + CCD	Yes
12, Poland	GE Innova 2000	Flat panel	To be performed
13, Cyprus	Mecall Superix 180 N	II + CCD	No
14, Slovakia	Siemens Artis dFC	Flat panel	No
	Chirana Chiraskop 2000	II + CCD	No
15, Estonia	Toshiba KXO-60G	II + CCD	No monitor on system
19, Bulgaria	Siemens Axiom Iconos MD	II + CCD	No

should be given explicitly in the protocol. It is recommended to include a way to indicate if a test is passed/failed and what are the consequences of failure. This latter recommendation holds also true for other parts of the protocol.

Automatic exposure control

The execution of tests of the automatic exposure control of the fluoroscopy systems by the participants is given in Table 5. In the protocol, the terminology should be adapted to digital equipment, e.g. the term 'image intensifier (II)' has to be replaced by 'image detector system (IDS)'. More extended tables in the protocol for IDS and patient incident air kerma will be useful. Performance criteria, if given in the protocol, are not applied by the participants to evaluate the results. The copper filter prescribed for the measurements can cause problems for FPD systems.

Table 3. System details provided by the participants.

Partner	2[a]	2[b]	8	11	12	13	14[a]	14[b]	15	19
Equipment										
Manufacturer	y	y	y	y	y	y	y	y	y	y
Make/model	y	y	y	y	y	y	y	y	y	y
Serial number	n	n	n	y	n	y	n	y	y	n
Screening tube	n	y	n	y	n	n	n	y	n	y
Over couch tube	n	n/a	n	n	—	n	n	y	y	n
Under couch tube			y		y					
Image intensifier	n	y	—	n	y	n	—	y	y	n
Flat panel detector			y	y	y		y			
Nominal rating	n	y	n	y	y	n/y	n	n	y	y
Nominal filtration	n	y	y	y	y	n	n	n	y	n
Installation date	n	y	y	y	y	n	y	y	y	y
Instruments										
Ionisation chamber	—	y[c]	—	—	—	—	y	y	y[c]	y[d]
Multimeter	—	y[e]	—	—	y[e]	—	y/y[f]	y/y[f]	y[e]/y[g]	—
Oscilloscope	—	—	—	—	y[j]	—	—	—	y[j]	—
Tube voltage meter	—	—	—	—	—	—	y	y	—	—
Leeds test objects	—	y[h]	—	—	—	—	y[h]	y[h]	—	y[i]

[a,b]Denote separate units by the same partner.
[c]Radcal 60 cc ionisation chamber.
[d]PTW Unidos E, 112 cc.
[e]Unfors Mult-O-Meter.
[f]Xi Unfors Mult-O-Meter.
[g]Baracuda MPD.
[h]Test objects from MPBE.
[i]Own Leeds test objects.
[j]Tektronics TDS 3012 or TDS 360.

Table 4. Tube and generator performance.

Partner	2[a]	2[b]	8	11	12	13	14[a]	14[b]	15	19
Tube output										
Constant current varying potential	n	1p[c]	y	n	[d]	[e]	[f]	y	y[g]	[e,f]
Constant potential varying current	n	[h]	—	n	y	n	y	y	y[g]	n
Tube output consistency	n	y	y	n	y	y	y	y	y	y
Tube potential										
Varying tube current at fixed tube voltage	n	[h]	n	n	n	n	[f]	y	y	n
Varying tube potential at fixed tube current	n	1p[c]	n	n	n	n	[f]	y	y	n
Specification of performance	n	n	n	n	n	n	n	n	n	n

[a,b]Denote separate units by the same partner.
[c]1p means at one tube potential.
[d]Alternative for AEC system, where tube voltage is varied and tube current varies automatically (table needs adaptation).
[e]Current cannot be stabilised.
[f]No manual control.
[g]Measured with two instruments.
[h]Not available.

Leeds test objects

The performance of tests on image quality using the Leeds test objects in the trial is given in Table 6. The Leeds test objects referred to in the protocol (GS2, N3, TO10, M1, MS1, MS3, MS4) are apparently replaced by a new series of phantoms (SW4, LCD4, TCD4, FSG4, SSM4). A statement should be added to the protocol that the latter series of phantoms can also be applied. For flat-panel detector systems, the shape of the test objects should be rectangular instead of circular in cross-section, since this does better fit the shape of the image detector. In some cases, phantoms with circular cross-sections cannot be used since they do not cover the whole detector field. As a consequence of this, parts of the FPD will be overexposed.

Table 5. Automatic exposure control.

Partner	2[a]	2[b]	8	11	12	13	14[a]	14[b]	15	19
II entrance dose rate	y[d]	y[d]	y[e]	n	n	n	n	n	y[d]	y[d]
According to specification of performance				n	—	n	—	—		
II entrance air kerma rate for 7 × 7 cm field	n	n	n	n	n	y	n	n	y	y
At each level of operation (push button control or maximum and minimum)	y	y	—	y	y	y	n	n	y	y[f]
At clinical settings	y	y	—	—	y	—	y[f]	y	n	n
At magnification settings	y	y[g]	—	y	y[h]	y	n	y	n	y
II entrance dose rate										
Pulsed fluoroscopy	y	y	y	n	y	y	y	n	n	y
Digital acquisition	—	y	—	—	—	—	—	—	—	—
Patient entrance dose rates	—	y	y	y	y	y	n	y	—	—
Maximum dose rate patient can receive	—	n	n	n	y	y	y	n	y	y
Pulsed mode and magnification settings	y	y[i]	y	y	n	y	y	n	n	y
Digital acquisition	—	y	n	n	n	n	n	n	n	n
Specification of performance	n	n	n	n	n	n	n	n	n	n

[a,b]Denote separate units by the same partner.
[c]Flat panel detector, only pulsed mode.
[d]Yes, but not concluded.
[e]Detector entrance dose rates do only fulfil entrance dose rate requirement for Fluoroscopy LD and ND and 6p/s.
[f]Values appear very high.
[g]Already in previous measurements.
[h]For pulsed mode.
[i]Adaptation of table needed.

Table 6. Leeds test objects.

Partner	2[a]	2[b]	8	11	12	13	14[a]	14[b]	15	19
Video voltage output	n	n/a	n	n	y	n	n	n	y[c]	n
Specification of performance	n	n/a	—	—	y[c]	—	—	—	y[d]	—
Grey scale test										
Number of steps visible	10	10	y	y	y	10	10	10	y	10
Black and white discs visible	y	y	y	y	y	y	2	y	y	y
Monitor adjustment	n	n	n	n	n	n	y	y	n	n
Specification of performance	y	—	—	—	—	—	—	—		—
Low contrast (noise) test object										
Number discs visible (full field)	11	10.5	9	10	11	11	9	10	10	15
Number discs visible (mag. 1)	11	12	10	10	11	12	9	11	n	14
Number discs visible (mag. 2)	11	12	10	10	11	12	9	11	n	14
Other kerma rates	n		y	n?	n	n	y	y	y	n
Specification of performance	y[c]	y[c]	n[d]	n[c]	n[c]	n[c]	n[d]	n[c]	n[c]	n[c]
New systems	n[d]	y[d][c]	n[d]	n[d]	n[d]	n[c]	n[d][c]	n[d]		n[c]
Contrast-detail test object										
Test performed?	y	y	n	y	y	y	y	y	y	y
Plot detection index values	y	y	n	n	n	n	n	n	n	n
Specification of performance	y[d]	n[d][d]	n[d]	n[d]	n[d]	n[d]	n[d][c]	n[d]	n[d]	n[d]
Field coverage test object										
Full field	y	y	y	n	y	y	y	y	y	y
Magn. 1	y	y	y	y	y	y	y	y	n	y
Magn. 2	y	y	y	y	y	y	y	y	n	y
S-distortion	y	y	y	n	y	n	y	y	y	y
Pincushion distortion	y	y	y	n	y	y	n	n	y	y
Specification of performance	n	n	y	n	y	n	n	n	y	y
Radiation field/image field	y	y	y	n	y	n	n	n	y	y
Specification of performance	y	y[c]	y	n	y	n	n	n	y	n
Inverse	y									
Limiting resolution test object										
Full field	y	y	—	—	y	—	—	—	y	y
Magn. 1	y	y	—	—	y	—	—	—	n	y
Magn. 2	y	y	—	—	y	—	—	—	n	y
Full field digital	y	y	—	—	—	—	—	—	—	—
Magn. 1 digital	y	y	—	—	—	—	—	—	—	—
Magn. 2 digital	y	y	—	—	—	—	—	—	—	—
Full field pulsed	—	n	y	y	—	y	y	y	—	y
Magn. 1 pulsed	—	n	y	y	—	y	y	y	—	y
Magn. 2 pulsed	—	n	y	y	—	y	y	y	—	y
Specification of performance	—	y[c]	y	y[c]	y[c]	y[c]	y[c]	y[c]	y[c]	y[c]
Specification of perform. digital	—	y[c][c]	—	—	—	—	—	—	—	—
Uniformity of focus test objects	—		—	—	—	—	—	—	—	—
MS1	y	n	y	y	n	n	n	n	y	y
MS3	y	n	y	y	n	n	n	n	n	y
MS4	y	y	y	y	n	n	n	n	n	y
Specification of performance	y	—	—	—	—	—	—	—	—	—

[a,b]Denote separate units by the same partner.
[c]Fulfilled but not indicated.
[d]Not fulfilled but not indicated.

The video voltage output test appeared difficult to perform (only two participants were able to do the QC measurement with this test object) since the measurement is too invasive for modern systems. It is, therefore, proposed to skip this test from the protocol for modern (digital) systems.

There are no specifications of performance for the grey scale test in the protocol. In the summary of the tests of system 2a (Table 7), requirements for the grey scale test are given. The test seems not very selective as all X-ray systems included in the trial do comply with the criteria in Table 7.

The low contrast (noise) test object performance criteria as specified for old systems are commonly complied with by the participants' X-ray systems. The low contrast (noise) test object performance

Table 7. A summary of the measurements on image quality for fluoroscopy system 2a using the Leeds test objects.

Test object	Requirement	Type of test	Test result
Grey-scale test object (GS2)	All 10 grey steps, black and white discs visible	Baseline	Satisfactory
Low contrast test object (N3)	FF: 0.033 M1: 0.033 M2: 0.033 M3: 0.030	<0.04	Pass, similar to previous inspection
Contrast-detail test object (TO10)	Graph	Baseline	Satisfactory, similar to previous inspection
Field coverage test object	FF: 0.80 M1: 0.89 M2: 0.88 M3: 0.93	0.85–1.0	Partial pass, similar to previous inspection
Limiting resolution test object (Hüttner)	FF: 1.25l p/mm M1: 1.70l p/mm M2: 2.00l p/mm M3: 2.80l p/mm	FF: $\geq$0.7l p/mm M1: $\geq$0.9l p/mm M2: $\geq$1.0l p/mm M3: $\geq$1.25l p/mm	Pass, similar to previous inspection
Uniformity of focus (Mesh test objects: MS1, MS3, MS4)	MS1: visible throughout MS3: visible throughout MS4: not visible	Baseline	Satisfactory
Equipment condition			Satisfactory

Note: It should be noted that some of the requirements given in the table are different from those in the protocol, i.e. for GS2 here a requirement is given; for N3 here only the requirement for old equipment is shown; for TO10 the graph does not fulfil the nominal values, although the results here are better than for the other units; for the field coverage test object the requirement is here as expected, i.e. one at maximum; here the requirements for the limiting resolution are less strict than in the protocol; for uniformity of focus here requirements are given, but not in the protocol.

criteria as specified for new systems are not complied with by the participants' equipment. This is surprising since most of the X-ray systems of the participants are relatively new.

None of the X-ray systems of the participants are capable of complying with the performance criteria for the contrast-detail test object. It seems that the criteria are too strict.

The field coverage test object seems too small. Instructions for scoring S-distortion and pincushion distortion should be added to the protocol.

The radiation field should be smaller than the imaged field. This means that the criterion as formulated in the protocol should be inverted.

The limiting resolution test object seems to be easy to use. The specification of performance is not always given by the participants.

Specifications of performance for the mesh phantoms are absent in the protocol and should be added, e.g. those given in Table 7.

CONCLUSIONS

Only one participant was able to perform the monitor test using MoniQA. This is due to the fact that assistance is apparently required from the suppliers of the X-ray systems. This problem needs to be solved to apply MoniQA in practice.

The MPBE protocol appeared to be useful for QC, and also for digital systems. It appears, however, that not all tests are useful or applicable for modern systems. The wording in some parts of the protocol needs to be adapted to the availability of digital systems. Performance requirements for some of the tests are not explicitly given and need to be added. The present protocol needs the addition of a section, or an addition to each section, to state compliance with the requirements. The circular cross sections of the Leeds Test Objects need adaptation for rectangular PFD systems.

ACKNOWLEDGEMENT

This project was partially supported by the European Radiation Protection Research Programme, part of the European Commission's Sixth Framework Programme (Contract 012909).

REFERENCES

1. The Institute of Physics and Engineering in Medicine (IPEM). *Recommended standards for the routine performance testing of diagnostic X-ray systems.* Report No. 77 (York: IPEM) (1997).
2. Institution of Physics and Engineering in Medicine and Biology (IPEMB). *Measurements of the performance characteristics of diagnostic X-ray systems used in medicine, X-ray image intensifier fluorography systems.* Report 32 Part VI (York: IPEM) (1996).
3. Bosmans, H., Carton, A.-K., Rogge, F., Zanca, F., Jacobs, J., Van Ongeval, C., Nijs, K., Van Steen, A. and Marchal, G. *Image quality measurements and metrics in full field digital mammography: an overview.* Radiat. Prot. Dosim. **117**, 120–130 (2005).