A New Tool for Benchmarking Cardiovascular Fluoroscopes

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ABSTRACT

This paper reports the status of a new cardiovascular-fluoroscopy-benchmarking-phantom. A joint working group of the Society for Cardiac Angiography and Interventions and the National Electrical Manufacturers Association (NEMA) developed the phantom. The device was adopted as NEMA standard XR 21-2000, "Characteristics of and Test Procedures for a Phantom to Benchmark Cardiac Fluoroscopic and Photographic Performance" in August 2000. The test ensemble includes imaging-field geometry, spatial resolution, low-contrast iodine detectability, working thickness range, visibility of moving targets, and phantom entrance dose. The phantom tests systems under conditions simulating normal clinical use for fluoroscopically guided invasive and interventional procedures. Test procedures rely on trained human observers.

FOREWORD

Defining and maintaining the quality of X-ray systems used in the cardiac catheterization laboratory (cath lab) has always been a priority for the Society for Cardiac Angiography and Interventions (SCA&I). The society ran a 'mail-order' testing program until the early 1990s. Some consulting groups continue to perform this test set in individual laboratories. The transition of imaging laboratories from cine-film to digital acquisition along with the increasing integration of computer controlled imaging systems necessitated the development of a new set of tools and procedures. In 1997, to obtain the broadest possible consensus, SCA&I requested the participation of the X-ray section of the National Electrical Manufacturers Association (NEMA). Virtually all of the manufacturers of cath lab equipment are represented in this section. Thus there was strong technical participation from industry. In addition, several SCA&I members, cath lab service staff members, and medical physicists contributed to this project.

The performance of any medical imaging system can be divided into two categories: Suitability of the images for the clinical procedure and the amount of energy administered to the patient while acquiring the images. Measurable differences in test performance may or may not reflect meaningful differences in clinical utility. Uncertainties included the variety of clinical tasks for which the equipment might be used, differences in the skills of operators, and the lack of congruence between the phantom and patient tissue.

All tests are performed using the imaging system configured for normal clinical use. The phantom and test procedures described here test systems under conditions simulating a range of fluoroscopically guided invasive and interventional procedures. The phantom loads the system, as does a similarly sized patient. Image quality test targets are placed at the center of the phantom (the clinically relevant region). In principle, all of the tests are performed simultaneously.

The major tests provide imaging targets with a range of visibilities. No system is expected

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\(a\) Presented on behalf of the NEMA – SCA&I working group

\(b\) New York, NY

\(c\) Cleveland OH

\(d\) Chicago, IL

\(e\) Rochester, MN
to image the least visible target in all or most of the tests. Indeed, the test ensemble and the requirement for simultaneous viewing of all tests precludes excessive optimization of any one set of targets. For example, too much image smoothing to improve low contrast detectability will degrade spatial resolution.

There is limited availability of optical, electronic, or digital techniques for evaluating imaging performance. Therefore, the test procedures in this standard are based on trained human observers. The United States Food and Drug Administration (FDA) has reached a similar conclusion in conjunction with their Mammography regulations.

The system level tools described in this paper are used to screen for inappropriate performance. Such tools are not always helpful in diagnosing the causes of such behavior. Supplementary tools can provide additional information about system or subsystem behavior. Equipment manufacturers have their own tools and procedures relevant to the setup and service of specific imaging systems.

The NEMA standard does not assign passing or optimum values for test performance. The equipment’s owner should determine an acceptable level of performance. As an alternative, recommended values might be given by experienced consultants or by independent testing organizations. Perhaps, these might eventually be established by entities such as equipment manufacturers, service organizations, professional societies, or regulatory agencies.

**PHANTOM and TEST DESCRIPTIONS**

The basic phantom material is Plexiglas (PMMA). This material has X-ray absorption and scatter properties that are similar to soft tissue. The approximation used in this document is that the PMMA thickness is equivalent to the same path-length in the patient. Configuring the phantom to different thickness simulates the range of patient sizes and imaging projection angles (Figures 1,2).

The phantom shown in this paper is a prototype. Production pieces will be slightly different in construction and appearance.

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Actual Field of View

A plate with suitable scales is placed on the entrance surface of the image intensifier. The plate is fluorographed using each available field of view. This determines the field-of-view of the image receptor.

The effective field-of-view for any source to image receptor distance (SID) is determined by placing the test plate at isocenter and obtaining fluorographs. Geometric magnification will reduce the field-of-view to a value less than that of the image receptor.

Congruence of Irradiated and Visualized Fields

A large sheet of film is placed between the field of view plate and the image receptor. The size of the irradiated field is determined by inspecting the processed film. A simultaneous fluorographic image confirms the size of the visualized field-of-view. This may be done with the test plate either at isocenter or at the entrance surface of the image receptor.

Spatial Resolution and Low Contrast Detectability

A standard bar pattern insert is included in the central test plate (Figures 3,4). This pattern is used to test spatial resolution. A target with discreet bars was selected to minimize the influence of aliasing on the observations. This 0.1 mm thick lead pattern provides sufficient contrast for use in the 30 cm phantom configuration. The lead content of this pattern has a small effect on the X-ray system's operating point.

Four sets of holes with diameters (4, 3, 2, 1 mm) are filled with elemental iodine imbedded in epoxy. The areal densities of iodine in the four patterns are 20, 10, 5, 2.5 mg/cm². The observer is required to identify the smallest visible pair of targets in each pattern.

Working Thickness Range

Video and digital signals may be either white or black clipped. The working thickness range tool provides a measure of this effect. Aluminum is used as a bone substitute for this test. Air cylinders are used to simulate lung. A cylinder is resolved if the target (lead or air respectively) can be seen within the cylinder (Figures 5,6). The specifications for the cylinders are given in Table 1.
Figure 5: Photograph of the central sections of the phantom. Air cylinders (H), air test pins (C), aluminum cylinders (J) and lead test pins (E) are shown.

Figure 6: Schematic drawing of the Working Thickness Range test. In this drawing there are two instances of black clipping and one instance of white clipping.

Table 1 Contents of working thickness range cylinders (200 mm total thickness phantom)

<table>
<thead>
<tr>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>175</td>
<td>150</td>
<td>125</td>
<td>100</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Al</td>
<td>--</td>
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<td>--</td>
<td>40</td>
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<td>50</td>
<td>50</td>
<td>160</td>
<td>153</td>
<td>147</td>
<td>140</td>
</tr>
</tbody>
</table>

* A1 – A4 and M1 – M4 refer to the four air cylinders and four aluminum cylinders found in the phantom.

Visibility of Moving Structures

A rotating spoke target allows visual evaluation of motion unsharpness and the effects of temporal averaging (Figures 7,8). The device contains five steel wires of different diameters (0.56, 0.41, 0.30, 0.23, 0.13 mm). Two lead dots are used to evaluate lag and recursive filtering. Rotation speed is 30 revolutions per minute. The linear velocity of the outer lead dot is 200 mm/s. The rotating disk replaces the central test plate at isocenter.

Dosimetry Tools

Dosimetry adapters allow measurement of the phantom entrance exposure (rate) at a standardized position in front of the entrance surface of the phantom (25 mm). The configuration of the phantom and probe location is shown in Figure 9. The reading is decreased because of loss of scatter from the phantom and increased because the measuring point is closer to the source than the entrance surface of the phantom. This position is considered an acceptable choice for this particular benchmarking phantom.

The phantom can also be configured to generate the FDA measuring point (30 cm in front of the image receptor). Additional plastic and lead is added to drive the system.
Figure 9: Phantom configuration for input dose measurements

to maximum output. In this case, the dosemeter probe is in exactly the prescribed position. The readings will be increased above 'in-air' measurements due to scatter from the phantom.

IMAGE ANALYSIS

Ideally, all test images should be computer analyzed. This can be done in principle for those systems with fluoroscopic and fluorographic DICOM outputs. The necessary software tools are under discussion.

A digital test solution is impossible given today's mix of analog and digital fluoro systems. The next best thing would be to incorporate tests that minimize operator bias. A forced-choice low-contrast detectability task is an example of such a test. Unfortunately, such a test is far too time consuming to incorporate in a phantom designed for rapid use.

The test results are dependent on the skill and training of the test operator. The best approach is to enroll testers in a formal training program before allowing them to work independently. This is precisely the route chosen by the FDA in their mammography testing regulations. Societies, such as SCA&I are expected to approve appropriate training programs for use of the NEMA phantom described in this paper.

DISCUSSION

This paper introduces an example of a new class of phantoms for evaluating fluoroscopic systems. It is based on an International Electrotechnical Commission draft standard on dose and image quality for all X-ray imaging systems. It is noteworthy that the design of the phantom reported in this paper represents a consensus including cardiologists, medical physicists, service engineers, and technical staff from all of the major imaging companies.

The Society for Cardiac Angiography and Interventions (SCA&I) initiated this project because of a need to reestablish a series of benchmarks for imaging system performance. Their intention is to establish a system performance registry based on phantom testing. A similar SCA&I registry, based on component testing, terminated in the early 1990s. Laboratories participating in this registry will receive reports showing their performance relative to the distributions in the entire database.

The entire database (with due regard to the confidentiality of the original data) will be periodically published. Over time, this project should provide useful information for reference doses and for reference levels of imaging performance.
Further Reading


ICRU Report 54 Medical Imaging: The Assessment of Image Quality 1996


