Image Quality and Exposure Control for Over-the-Table X-ray Systems Using a Flat-panel Detector

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Abstract: Quality control (QC) is essential for ensuring that the X-ray images produced by fluoroscopy systems are of sufficient quality to provide adequate diagnostic information consistently with the least possible radiation exposure. However, there are limited data on QC (image quality and radiation exposure) in fluoroscopy systems with over-the-table X-ray tubes. We describe a QC protocol for over-the-table fluoroscopy systems. We checked the image quality of over-the-table system using QC phantoms. In this study, over-the-table X-ray system with a flat-panel detector (FPD) was used. The X-ray outputs (i.e., kVp, mA, pulse width) of over-the-table system were evaluated simultaneously. Some QC data (e.g., radiation output and image quality) were scattered, especially when a smaller QC phantom was used, because AEC errors may occur due to inconsistent measurement geometry. Thus, we recommend the use of a phantom holder and beam-limiting tool with a small QC phantom to maintain the measurement geometry of the phantom and X-ray beam. QC is important for over-the-table fluoroscopy systems, as well as under-the-table systems. We cannot ignore QC in over-the-table systems. Generally, the QC protocol for over-the-table systems should be the same as that for under-the-table systems.

Keywords: Flat Panel Detector (FPD), Quality Control (QC), Phantom, Fluoroscopy, Angiography, Over-the-Table X-ray Tube, Image Quality, X-ray Dose

1. Introduction

Quality control (QC) is essential in ensuring that X-ray images produced with fluoroscopy systems are of sufficient quality to provide adequate diagnostic information, consistent with the lowest possible radiation exposure [1-10]. However, limited data on QC are available in terms of image quality and radiation exposure in fluoroscopy systems with over-the-table X-ray tubes. We describe a QC protocol for over-the-table fluoroscopy systems. In this study, over-the-table X-ray system with a flat-panel detector (FPD) was used. The X-ray outputs (i.e., kVp, mA, pulse width) of over-the-table system were evaluated simultaneously. Some QC data (e.g., radiation output and image quality) were scattered, especially when a smaller QC phantom was used, because AEC errors may occur due to inconsistent measurement geometry. Thus, we recommend the use of a phantom holder and beam-limiting tool with a small QC phantom to maintain the measurement geometry of the phantom and X-ray beam. QC is important for over-the-table fluoroscopy systems, as well as under-the-table systems. We cannot ignore QC in over-the-table systems. Generally, the QC protocol for over-the-table systems should be the same as that for under-the-table systems.

Keywords: Flat Panel Detector (FPD), Quality Control (QC), Phantom, Fluoroscopy, Angiography, Over-the-Table X-ray Tube, Image Quality, X-ray Dose

2. Materials and Methods

We checked the image quality of over-the-table system...
using QC phantoms (JSGI phantom and KC-001 phantom).

In this study, over-the-table X-ray system (ZEXRA FPD Version, Toshiba, Japan) with a flat-panel detector (FPD) was used.

2.1. JSGI Phantom

Figure 1 shows a commercial JSGI phantom for checking image quality [28]. This phantom consists of a copper base (thickness, 2.0 mm), acrylic holes and protrusions (diameters, 3 and 5 mm) of various thicknesses (0.25–3 mm), and a square wave chart for determining visual resolution by line-group tests (line widths, 0.15–0.5 mm; Figure 2). The phantom size is $10 \times 10 \text{ cm}^2$. This QC phantom can aid in the visual evaluation of spatial and low-contrast resolutions.

2.2. X-ray Output Check

X-ray output (kV, mA, s) can be checked using the values displayed on the X-ray apparatus. These values were not preset in the unit. The displayed values were obtained using the built-in measurement circuitry of the high-frequency X-ray generators.

2.3. Phantom Holder and Beam-Limiting Tool

Changes in measurement geometry (beam collimation size and phantom position) can cause errors in automatic exposure control (AEC), such as the system being unable to maintain the correct X-ray output, and/or direct X-ray emission incident to the AEC region of interest (ROI) on the FPD that is not absorbed by the phantom makes the emission appear smaller.

Thus, we next made a customized phantom holder and
beam-limiting tool to maintain the measurement geometry of the phantom and X-ray beam (Figure 3). The beam-limiting tool consisted of 3-mm-thick copper and was attached to the port of the collimation device; consequently, the radiation field size was 10 × 10 cm at the JSGI phantom. The JSGI phantom holder consisted of a vinyl mat and was attached to the patient support table.

The X-ray exposure factors were as follows: distance between source and FPD, 100 cm; distance between source and phantom surface, approximately 75 cm; and fluoroscopic pulse rate, 15 p/s.

Figure 4. Appearance of the simple quality control phantom (KC-001) used to evaluate flat-panel detector image performance (spatial resolution, low-contrast detectability, and dynamic range).

2.4. Daily Monitoring of an FPD System over 3 Months Using a QC Phantom (KC-001)

We also performed daily checks of an over-the-table system with an FPD, using an KC-001 phantom instead of the JSGI phantom. The FPD phantom (KC-001) was 20 × 20 cm² (Figure 4) and consisted of three thicknesses (0.5, 1.5, and 3.0 mm) of copper, an aluminum step wedge (0.1–2.7 mm; hole diameters, 10 mm), and piano wire of various diameters (0.08–0.5 mm; Figure 5) [29]. The QC phantom (KC-001) for FPD systems can be used to evaluate spatial resolution, low-contrast resolution, and the dynamic range of a single X-ray exposure. We also performed daily monitoring of the over-the-table X-ray systems with FPDs (fluoroscopic and radiographic images) using the phantom.

Figure 5. X-ray images of the flat-panel detector phantom (KC-001).

3. Results

3.1. QC Data Using the JSGI Phantom Holder and Beam-Limiting Tool

Figure 6 shows daily X-ray output data (fluoroscopic pulse widths) over 3 months for an over-the-table system under the same conditions, obtained using the JSGI phantom holder and the beam-limiting tool. Pulse widths were not scattered (mean ± SD, 7.73 ± 0.21 ms; SD/mean, 0.03).

Thus, the phantom holder and beam-limiting tool were useful when a smaller phantom (JSGI) was used.

Figure 7 shows daily monitoring data for image quality (spatial resolution) of an over-the-table system obtained using the JSGI phantom under the same conditions. Data for the X-ray system illustrated in Figures 6 and 7 showed no abnormality (no missing data) over the time period.

Figure 6. Example of daily X-ray output data (fluoroscopic pulse widths) for an over-the-table system, obtained using the JSGI phantom with the phantom holder and beam-limiting tool under the same conditions.
3.2. KC-001 Phantom

Figure 8 shows daily X-ray output (pulse width) data for an over-the-table system obtained using the KC-001 phantom under the same conditions. Pulse widths were not scattered (mean ± SD, 6.01 ± 0.08 ms; SD/mean, 0.01), even when the phantom holder and beam-limiting tool were not used. Because the FPD phantom was larger than the JSGI phantom, AEC errors did not occur despite slight changes in measurement geometry because direct X-rays were not incident to the FPD (ROI for AEC).

Figure 9 shows daily image quality data (visual spatial resolution scores) for an over-the-table system obtained using the FPD phantom under the same conditions. Using this phantom, we readily evaluated the performance of the FPD system, including spatial resolution (using the piano wires), low-contrast resolution (using the aluminum step wedge), and dynamic range [using the aluminum step wedge and thin and thick (0.5- and 3.0-mm) pieces of copper].

4. Discussion

Examples of abnormal QC data

Figure 10 shows example data for daily checks of fluoroscopic X-ray output (tube currents) of an over-the-table fluoroscopy system using the QC phantom (JSGI). This monitoring allows the detection of abnormal QC data and, with service engineer assistance, the maintenance of optimal X-ray conditions. QC for over-the-table fluoroscopy systems is generally necessary.

KC-001 phantom

This phantom is more useful than the JSGI phantom for QC of an FPD system because it enables visual evaluation of image performance for three thicknesses of copper (low, intermediate, and high attenuation). Additionally, spatial resolution can be evaluated more readily using the FPD phantom (using piano wire of various diameters) than using the JSGI phantom (using a square wave chart). Furthermore, the FPD phantom enables detailed evaluation of image quality because it has many different objects, yielding a wider range of visual scores (0 to >10) than does the JSGI phantom (0 to 5).

QC protocol for over-the-table X-ray systems

We believe that QC protocols for over-the-table X-ray systems should generally be the same as those for under-the-table X-ray systems. The QC protocol should include the monitoring of image quality (spatial resolution, low-contrast resolution, dynamic range), X-ray output (dose, kV, mA, and exposure time/pulse width), and the display monitor (e.g., luminance). Monitoring of X-ray output using a QC tool (QC solution) is also useful [30, 31].

In conclusion, QC is important for over-the-table fluoroscopy systems, as well as under-the-table systems. Some QC data (e.g., radiation output and image quality) were scattered, especially when a smaller QC phantom was used, because AEC errors may occur due to inconsistent
measurement geometry. Thus, we recommend the use of a phantom holder and beam-limiting tool with a small QC phantom to maintain the measurement geometry of the phantom and X-ray beam. We recommend the use of an KC-001 phantom for QC of an FPD system, which enables evaluation of the wide dynamic range of the FPD. Generally, the QC protocol for over-the-table systems should be the same as that for under-the-table systems.

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References


