

Functionality and operation of fluoroscopic automatic brightness control/automatic dose rate control logic in modern cardiovascular and interventional angiography systems: A Report of Task Group 125 Radiography/Fluoroscopy Subcommittee, Imaging Physics Committee, Science Council

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Task Group 125 (TG 125) was charged with investigating the functionality of fluoroscopic automatic dose rate and image quality control logic in modern angiographic systems, paying specific attention to the spectral shaping filters and variations in the selected radiologic imaging parameters. The task group was also charged with describing the operational aspects of the imaging equipment for the purpose of assisting the clinical medical physicist with clinical set-up and performance evaluation. Although there are clear distinctions between the fluoroscopic operation of an angiographic system and its acquisition modes (digital cine, digital angiography, digital subtraction angiography, etc.), the scope of this work was limited to the fluoroscopic operation of the systems studied. The use of spectral shaping filters in cardiovascular and interventional angiography equipment has been shown to reduce patient dose. If the imaging control algorithm were programmed to work in conjunction with the selected spectral filter, and if the generator parameters were optimized for the selected filter, then image quality could also be improved. Although assessment of image quality was not included as part of this report, it was recognized that for fluoroscopic imaging the parameters that influence radiation output, differential absorption, and patient dose are also the same parameters that influence image quality. Therefore, this report will utilize the terminology "automatic dose rate and image quality" (ADRIQ) when describing the control logic in modern interventional angiographic systems and, where relevant, will describe the influence of controlled parameters on the subsequent image quality. A total of 22 angiography units were investigated by the task group and of these one each was chosen as representative of the equipment manufactured by GE Healthcare, Philips Medical Systems, Shimadzu Medical USA, and Siemens Medical Systems. All equipment, for which measurement data were included in this report, was manufactured within the three year period from 2006 to 2008. Using polymethylmethacrylate (PMMA) plastic to simulate patient attenuation, each angiographic imaging system was evaluated by recording the following parameters: tube potential in units of kilovolts peak (kVp), tube current in units of milliamperes (mA), pulse width (PW) in units of milliseconds (ms), spectral filtration setting, and patient air kerma rate (PAKR) as a function of the attenuator thickness. Data were graphically plotted to reveal the manner in which the ADRIQ control logic responded to changes in object attenuation. There were similarities in the manner in which the

ADRIQ control logic operated that allowed the four chosen devices to be divided into two groups, with two of the systems in each group. There were also unique approaches to the ADRIQ control logic that were associated with some of the systems, and these are described in the report. The evaluation revealed relevant information about the testing procedure and also about the manner in which different manufacturers approach the utilization of spectral filtration, pulsed fluoroscopy, and maximum PAKR limitation. This information should be particularly valuable to the clinical medical physicist charged with acceptance testing and performance evaluation of modern angiographic systems. © 2012 American Association of Physicists in Medicine. [<http://dx.doi.org/10.1118/1.4704524>]

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EXECUTIVE SUMMARY

Fluoroscopic x-ray systems make use of a set of rules (algorithms) that control the system's response to dynamic changes in imaging conditions. Usually, these control algorithms maintain the absorbed energy fluence per pixel at the imaging detector's x-ray capture layer, resulting in a reasonably constant average signal level from the detector. The absorbed energy fluence per pixel is maintained by controlling the exposure parameters of the x-ray generator such that a constant, predefined detector signal level is achieved. The control of generator exposure factors to maintain a constant image receptor output signal is often called the automatic brightness control (ABC) or automatic dose rate control (ADRC) mode of operation. Angiographic systems are designed to ensure that a change in exposure parameters does not result in settings that would exceed the design limits of the x-ray generator nor the heat rating of the x-ray tube. In addition, the allowed combinations of generator parameters are such that radiation exposure rates do not exceed the regulatory limits.

The use of spectral shaping filters in the fluoroscopic imaging procedures of cardiovascular and interventional angiography equipment has been shown to reduce patient air kerma (PAK) while maintaining fluoroscopic image quality and extending the dynamic range in patient thickness. With traditional x-ray image intensifier (XRII) fluoroscopic imaging systems, the operator controlled the exposure production via a footswitch while observing the dynamic image display through an optical lens or television display. The factors that played a role in limiting XRII imaging performance included a single preset image intensifier input exposure rate; a fixed optical aperture; limited image processing; predefined image display parameters, fixed beam filtration, the use of anti-isowatt power curves, and limitations in the rate of heat input to the x-ray tube. Image quality was affected by the fact that moving objects imaged with continuous fluoroscopy were blurred over the 33.3 ms integration time of the image, and contrast was degraded. Modern fluoroscopy systems employ pulsed fluoroscopy, which has the potential to improve temporal resolution via the use of a short pulse width. Such systems also have the means of controlling the XRII optical aperture, the PW, the beam filtration, and even the input dose to the detector in addition to controlling the kVp and mA generator parameters. The control of additional parameters

beyond kVp and mA make modern system more complex. However, understanding how the modern automatic brightness control/automatic dose rate and image quality control logic (ABC/ADRIQ) functions is integral to any attempt to optimize the balance between patient dose and image quality.

The focus of AAPM Task Group 125 was to explore and investigate the functionality of fluoroscopic ABC/ADRIQ in modern cardiovascular and interventional angiography systems (hereafter designated "angiography systems"). The TG 125 report provides an understanding of how generator control logic, aggressive spectral filtration, and imaging parameters are programmed to work together to maintain or improve image quality while reducing the patient skin dose.

Since the parameters that are utilized by the ABC/ADRIQ control logic to maintain a constant average detector signal are also the same parameters that govern the x-ray tube output intensity and photon energy spectrum, it is important to consider the impact of the control logic on the types of radiation exposure involved in fluoroscopic imaging. The report identifies four types of radiation exposure that are of interest when considering fluoroscopy as a visualization device for diagnostic and therapeutic procedures. These are (1) the entrance exposure rate to the detector (EERD), (2) the nominal patient skin entrance exposure rate (SEER), (3) the maximum patient SEER, and (4) the scattered radiation from the patient and other materials in the path of the x-ray beam. The TG 125 report describes the impact of the ABC/ADRIQ control logic on each of these exposure types. For example, if the EERD is too low, the image will suffer from increased noise; if too high, the patient dose will be unnecessarily high, although the image quality (SNR^2) will be improved. Discussions of SEER would normally be accompanied by a discussion of the fluoroscopic image quality. However, owing to the complexity of the imaging control logic (e.g., as many as 60 parameters are controlled in order to ensure optimization of image quality), a suitable imaging phantom would need to be defined that would be capable of assessing image quality with any commercially available imager and without bias. The TG 125 report makes it clear that the patient SEER depends on both the spectral filtration utilized and on the generator operating curve. It is revealed that this concept was the principle behind the design and operation of modern ABC/ADRIQ control logic. The TG 125 report illustrates the manner in which various manufacturers have

created combinations of spectral filtration and generator control curves to optimize their imaging systems.

A lesser known feature of fluoroscopy systems, the SID output compensation, is also described. As the SID is varied, this control circuit adjusts the maximum radiation output, determined at the FDA specified measurement point, in accordance with the x-ray tube load limits and the regulatory maximum exposure rate requirements. It is also revealed that for some systems a minimum detector signal must be obtained or else the fluoroscopic exposure is terminated. This impacts the ability of the medical physicist to measure and document regulatory compliance with the maximum allowed radiation exposure rate.

All equipment investigated by the task group utilized combinations of Al and Cu spectral beam filtration. It was found that there are two general approaches to the implementation of spectral beam filtration in fluoroscopy, and these are referred to as the "traditional" method and the "program-switched" methods. The traditional method refers to a fixed, factory installed filter. The program-switched method is an automated form of the traditional method in which predetermined combinations of added spectral filtration can be automatically switched under program control. The selection of a specific spectral filter will be linked to the anatomically based protocol setting and also to the fluoroscopy dose rate or pulse rate control setting. Once a fluoroscopy mode, dose rate, and pulse rate are selected, the spectral filtration determined by the control logic is independent of the variations in patient attenuation. However, for one system in the study, it was found that the spectral filtration automatically changed whenever the SID exceeded a predetermined value. Since the amount of spectral filtration is under program control, the user may not be aware of how much filtration is in the beam for a given patient, protocol, beam geometry, and dose setting.

The equipment available to the task group members was limited to (in alphabetical order) GE Healthcare (4 units), Philips Medical Systems (5 units), Shimadzu Medical USA (1 unit), and Siemens Medical Systems (12 units). The numbers in the parentheses correspond to the number of imaging systems evaluated. After preliminary analysis of the data collected, one representative system from each of the four manufacturers was selected and included in the report. All of the selected systems utilized the most recent software version available at the time. For consistency, the cardiac "coronary" angiogram program on each machine was selected for the data collection, and the default startup settings were employed with the exception of the field of view (FOV). The selection of FOV was based on the *de facto* standard image intensifier size of 23 cm (9 in.), which have been installed in most cardiovascular angiography laboratories in the past decade. Although none of the systems used for data acquisition had a 23 cm FOV selection available, the FOV that was closest to 23 cm in the diagonal dimension was chosen for the evaluation setup. The SID was set to 120 cm or the maximum

SID available on the system being investigated. The fluoroscopic imaging parameters kVp, mA, PW, spectral shaping filter, and PAKR were recorded as a function of the attenuator thickness, as the PMMA thickness was increased in 1.27 cm (0.5 in.) increments. For the GE and Siemens systems, there were discrete transition points where the amount of beam filtration abruptly changed. In order to capture the discontinuity points of the changing imaging parameters associated with the change in spectral shaping filter thickness, PMMA increments of 0.635 cm (0.25 in.) were utilized to pinpoint the PMMA thickness where the ABC/ADRIQ produced a change in spectral filtration.

For the Philips and Shimadzu systems, the filtration associated with the selected program remained constant regardless of the thickness of PMMA. For these two systems, the type and thickness of filtration was determined by the anatomical protocol selected, and the filter did not vary as the patient attenuation changed. There were no sudden changes in primary beam intensity that would otherwise be caused by the changing spectral shaping filter. Information about the imaging systems from Toshiba America Medical Systems and Hitachi Medical Systems was obtained and reviewed, but due to the lack of access to clinical systems from these manufacturers, no test data were obtained.

Most diagnostic instruments used for measuring patient/phantom skin dose are calibrated using the IEC defined RQR series of x-ray beams. Instruments used for measuring image-receptor input dose are typically calibrated using RQA x-ray beams. The systems described in this report were all highly filtered with combinations of Cu and Al, with two systems also utilizing a high atomic number material. The x-ray spectra from these systems therefore did not conform to either the RQR or the RQA standard beam quality. In fact, it was determined that there is a lack of standard beam qualities available for calibration of ionization chambers to the beam spectra being employed in clinical fluoroscopy systems designed for angiographic imaging.

The evaluation conducted by TG 125 revealed relevant information about the testing procedure and also about the manner in which different manufacturers approach the utilization of spectral filtration, pulsed fluoroscopy, and maximum PAKR limitation. It is hoped that the information provided in the TG 125 report will enhance the practicing medical physicists' working knowledge and will thus facilitate their ability to understand the design of modern angiographic systems. The report should also provide the clinical physicist with an understanding of the differences between modern and legacy fluoroscopy systems and how these differences affect the evaluation and performance testing procedures for modern systems. Please consult the full Task Group 125 report for more information.

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