SIEMENS

White Paper

Low-dose imaging is becoming a clinical reality

Introduction

The number of lengthy minimally invasive endovascular procedures has increased significantly over the last years (1). These cardiovascular, neurovascular, and oncologic procedures often require the acquisition of many high-quality digital subtraction or non-subtraction angiography image sets. Long total fluoroscopy times often associated with such procedures can result in patients and staff being exposed to considerable radiation dose levels. The use of *syngo* DynaCT® (cone beam CT) is increasing especially during neuro and oncologic endovascular therapy (2). In light of patient and staff safety, the ALARA principle (As Low As Reasonably Achievable) must be understood and followed whenever ionizing radiation is used. In this context, one should always consider the balance of dose and image quality (IQ) to provide good visualization of the anatomy and pathology at the lowest possible dose.

All Siemens angiography systems provide low dose protocols in angiography and fluoroscopy for all anatomical regions. To maximally support the ALARA principle and achieve low dose[1] protocols, the detector entrance dose setting must be lowered. Within the last ten years, the requested detector entrance dose for low-dose imaging has been reduced by up to 85% (Figure 1).

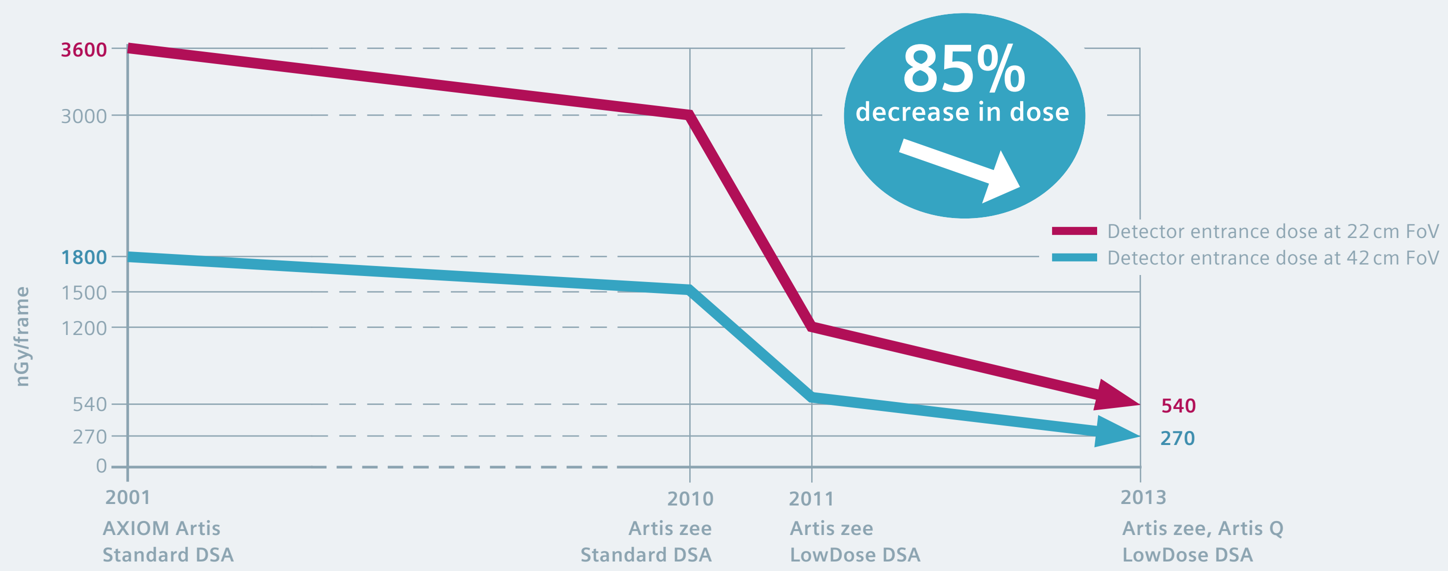


Figure 1: The detector entrance dose for standard DSA examinations has decreased significantly from AXIOM Artis (2001) to Artis zee and Artis Q (2013). Siemens uses 22 cm Field of View (FoV) as a reference format for standardized dose display. At this format, the dose went down from 3600 nGy/frame to only 540 nGy/frame.

[1] In this document "dose" means air kerma.

Answers for life.

However, since lesion detectability is directly related to detector entrance dose, Siemens has invested significantly in innovations in tube, detector, and the imaging chain to maintain diagnostically reliable image quality at the lowest possible dose levels (Figure 2).

In addition to high performance X-ray tubes and the advanced flat detectors other important factors also play a role in low-dose imaging:

- Advanced Exposure Control (AEC) supported by CARE[2] adjusts the X-ray parameters to enable the best possible image quality, while keeping the dose as low as possible.
- State-of-the-art real-time processing (CLEAR[2]) creates images with good object visibility and the fewest artifacts possible even at these extremely low dose settings.
- Intelligent fluoroscopy with low dose, pulsed fluoroscopy, and other CARE+CLEAR features are also key in achieving fluoroscopy exams with the ALARA principle.
- The dose monitoring and CAREguard features provide both visual and audible warnings so users of the angiography system are more careful with X-ray use, especially during fluoroscopy.

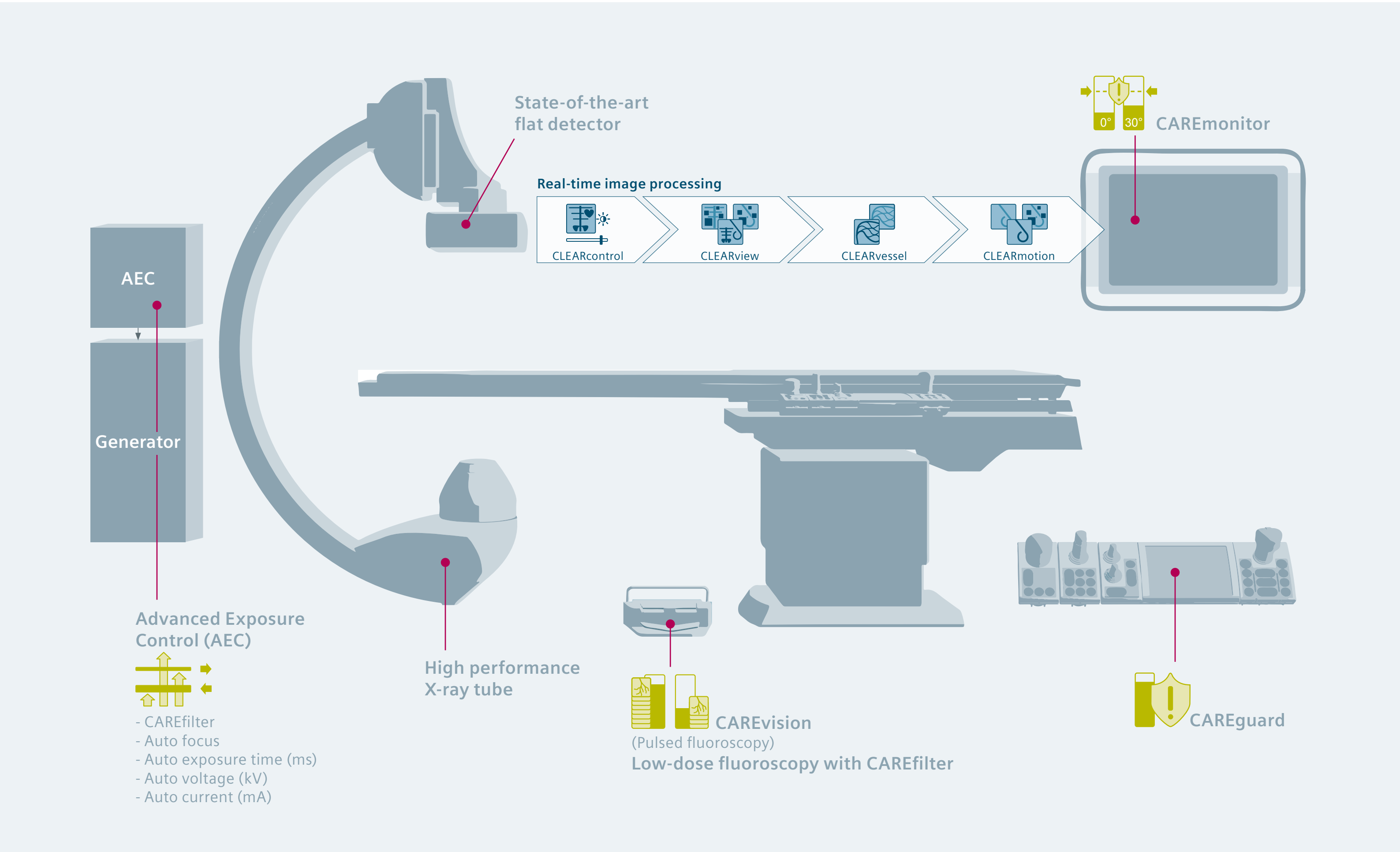


Figure 2: Siemens has achieved a dramatic reduction in dose due to developments in the X-ray tubes, detectors, advanced exposure control (AEC), real-time image processing (CLEAR), intelligent fluoroscopy techniques, and dose monitoring.

[2] CARE+CLEAR is the comprehensive portfolio of image quality and dose-saving tools – and is standard with Artis systems. CARE+CLEAR provides Siemens users with their preferred image quality at the lowest possible dose, supporting confident decisions in diagnosis and treatment as well as increasing the safety of both patients and clinical staff.

Advanced exposure control

Advanced exposure control (AEC) is vital to keep image quality consistent for all examination types while automatically compensating for patient size. The Siemens AEC estimates the patient thickness in real time. Variations in patient size, anatomical area, and C-arm angulation are automatically considered when calculating the needed dose. Based on this measurement, the detector entrance dose is kept constant due to an automatic and real-time adjustment of the following five parameters (Figure 3):

1. Tube voltage
2. Tube current
3. Pre-filter (CAREfilter)
4. Exposure time (pulse width)
5. Focal spot

Siemens uses a 22 cm Field of View (FoV[3]) as a reference format for detector entrance dose. The actual dose display in the images ("D value") is based on this reference format. During an examination with different FoVs, the requested dose at the detector entrance is adjusted to the FoV selected as shown below for a 30x40 detector:

- 48 cm FoV: dose at reference format x 0.5
- 42 cm FoV: dose at reference format x 0.5
- 32 cm FoV: dose at reference format x 0.7
- 22 cm FoV: dose at reference format x 1.0
- 16 cm FoV: dose at reference format x 1.4
- 11 cm FoV: dose at reference format x 2.0

For example, for a DSA exam with 48 cm or 42 cm FoV, the dose value set in the organ protocol must be multiplied by 0.5 to receive the requested dose at the detector (Figure 4). In order to compare to other vendors, this rule must be kept in mind.

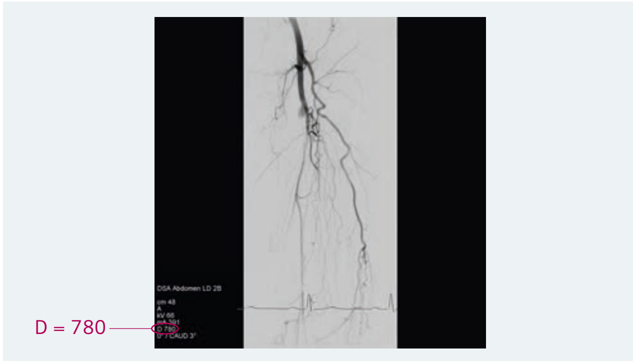


Figure 4: D = 780 nGy/frame shows standard dose measurement at 22 cm FoV. The real detector entrance dose at 48 cm FoV is calculated as 780 nGy/frame x 0.5 = 390 nGy/frame.

Unlike other systems on the market where only two parameters (kV and mA) can be changed, Siemens systems allow for dynamic, online adjustment of five parameters (kV, mA, ms, pre-filtration,focal spot size), automatically performed by the system itself. This results in optimal reduction of radiation dose and consistent image quality compatible with the ALARA principle and allows users to perform a wide range of procedures at low dose for all patient sizes – from pediatric use to coronary interventions in obese adults. We will take a detailed look at the advanced parameters of AEC on the following pages.

Figure 3: Advanced exposure control (AEC) and the principle of dose regulation with constant detector entrance dose. AEC analyzes the actual detector entrance dose and automatically adjusts five parameters in context of the organ program selected to keep the detector entrance dose at the required level and to provide the best image quality possible.

[3] FoV is detector diagonal measurement.

Effect of copper filter thickness on patient entrance dose

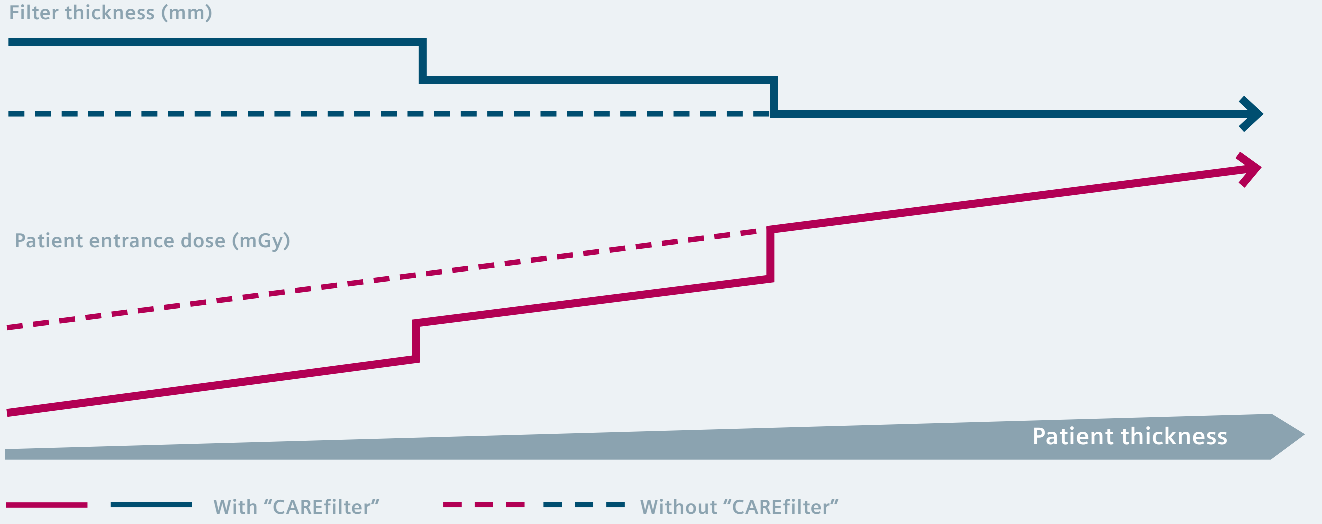


Figure 5: Comparing CAREfilter (blue arrow) to fixed pre-filtration (dashed blue arrow) and their effects on dose (red arrow and red dashed arrow): Siemens customers benefit from reduced patient entrance dose in thinner patients (due to high pre-filtration) and from better image quality in larger patients (due to low pre-filtration). CAREfilter automatically adjusts the pre-filter dynamically to different patient sizes by starting with the thickest filter for thin patients and gradually decreasing the filter thickness as the patient anatomy gets larger. Small patients and examination of thin body parts clearly benefit from the higher filtration with CAREfilter at lower patient entrance dose compared to fixed pre-filtration (dashed red arrow).

CAREfilter

Since 1994, CAREfilter is the Siemens term to describe the automatic insertion of the optimal copper pre-filtration. The theory of operation can easily be explained as follows: The thinner the patient, the more copper is inserted into the beam – resulting in a lower patient entrance dose by filtering out low energy radiation.

Artis systems use a dynamic copper filtration system to reduce low-energy radiation in the X-ray beam. The thickness of the copper filter ranges from 0 mm to 0.9 mm and the AEC automatically adjusts the copper filtration (Figure 5). It is important to note that copper is more efficient in reducing patient dose than aluminum (3).

With Artis systems, dose reduction is active right from the start of a procedure because the copper filter is moved into position before the first images are taken. During the procedure, the pre-filter setting is based on a real-time absorption measurement of the object in the beam. As the Siemens' AEC takes patient size, density of the anatomical region irradiated into account, the appropriate pre-filtration setting is automatically selected without any user interaction, thus yielding an optimized dose to the patient. For example, during a pediatric cardiac examination: If the direction of projection is changed from oblique to anteroposterior, the filter thickness automatically increases since the volume of the area to be examined has decreased and the distance the X-ray has to penetrate the patient's tissue has decreased during the change of the angulation. The increased filter thickness will lead to lower patient dose.

For every fluoroscopic and acquisition protocol, there are settings which determine the desired kV plateau as well as the minimal and maximal copper filter thickness. In general, it can be said that the higher the kV, the lower the image contrast. So in addition to the copper filtration, the system also adapts the kV (radiation penetration) to the patient thickness in order to maintain a constant image quality. For example, whenever the kV required for penetrating the patient exceeds the predefined kV threshold, copper is removed until the given limits are met. This kV threshold helps maintain a good image contrast.

Exposure time (pulse width)

The Artis systems' AEC has "automatic exposure time optimization". Whenever the necessary tube dose output can be provided with a shorter pulse width, exposure time is automatically reduced. This leads to less motion blurring, which also allows lower dose for the patient[4] (Figure 6).

[4] The dose reduction for the patient reflects a lower patient entrance dose.

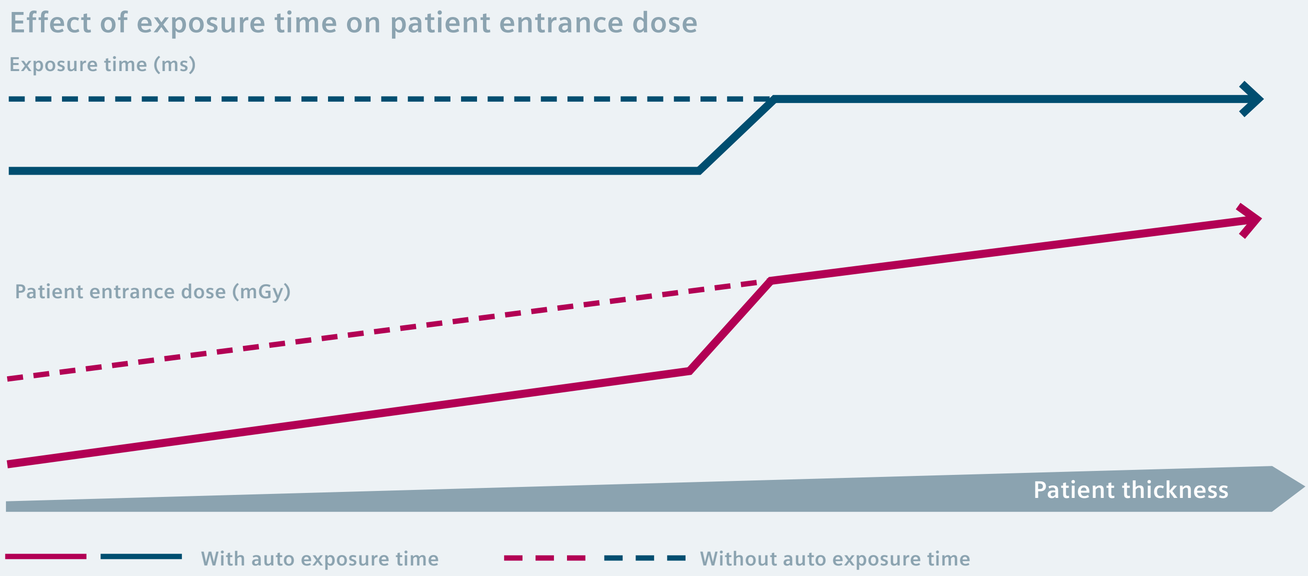


Figure 6: Comparing auto exposure time (blue arrow) to fixed exposure time (dashed blue arrow) and their effects on patient entrance dose (red arrow and red dashed arrow): Siemens customers benefit from reduced patient entrance dose (red arrow) in thinner patients and a better image quality for moving objects (e.g. coronaries) due to less motion blur. With the help of the automatic exposure time optimization, a shorter pulse can be used for thinner patients compared to fixed exposure time. With fixed exposure time, the dose will remain higher (dashed red arrow) for thinner patients.

Focal spot

The Artis systems' exposure control provides an automated focal spot selection (Figure 7). Whenever the necessary tube dose output can be provided by a smaller focus, the focal spot is automatically switched to a smaller focus. The result is a higher spatial resolution in the image, which usually coincides with lower patient dose. The automatic selection of the focal spot size enhances image quality (Figure 8) due to optimization based on the thickness of the examined area (patient size or angulation change). Workflow efficiency can also be improved as this functionality requires no user interaction. The Siemens X-ray tubes provide up to three different focal spot sizes with the smallest focal spot size of 0.3 mm (micro focus). This permits ideal adjustment to a wide range of needs, e.g. very high resolution for pediatric and neuro interventions and maximum power for obese adults.

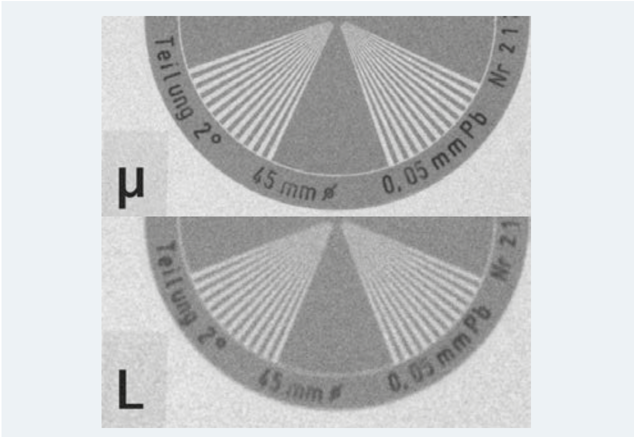


Figure 8: Micro focus (µ) provides better image quality compared to larger focus (L)

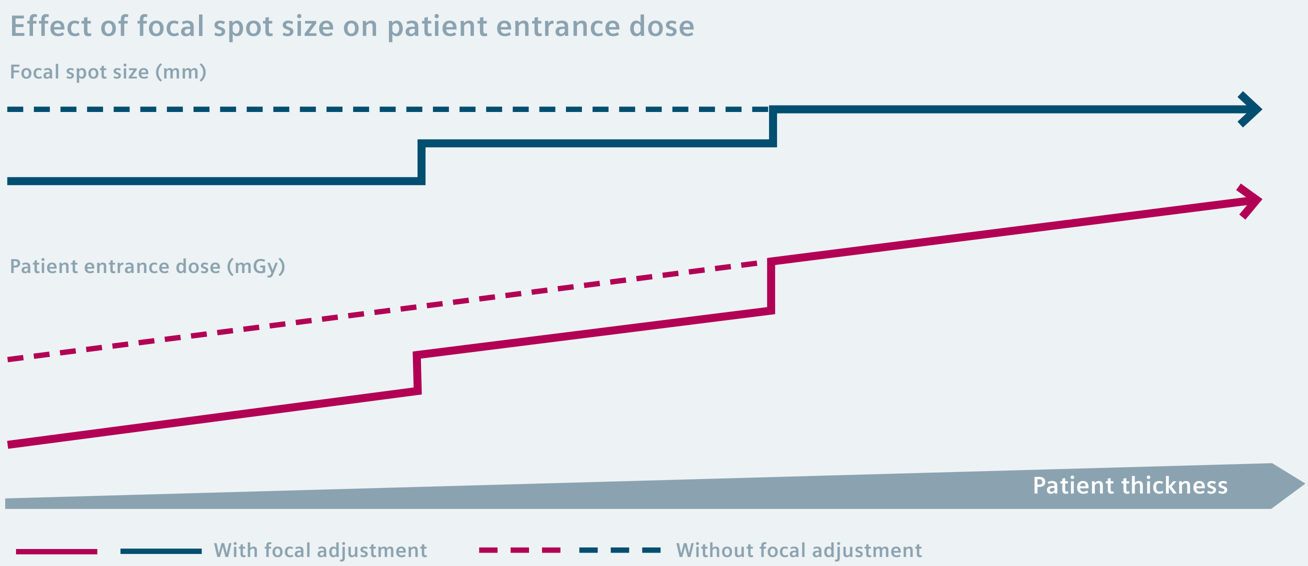


Figure 7: Comparing focal spot adjustment (blue arrow) to a fixed focal spot (blue dashed arrow) and their effects on dose: The Siemens X-ray tubes provide up to three different focal spots. The active focal spot is automatically changed based on patient thickness and parameters defined in the active protocol (blue arrow). The use of smaller focal spots results in lower patient entrance dose (red arrow) and better image quality for small objects (e.g. high order vessel branches). Without auto focus adjustment, the dose will stay higher (dashed red arrow) for thinner patients.

CLEAR: Advanced processing in angiographic imaging

As mentioned in the previous section, dose can be optimally reduced by adjusting five parameters with the help of AEC. However, the image outcome may still have some artifacts due to low-dose detector settings and motion. This section explains how image processing enhances image quality – especially for low-dose images – by reducing noise, increasing image sharpness, and compensating for motion artifacts.

By optimizing real-time image processing, a given image quality can be achieved at a lower dose level or a better image quality at a given dose level. For this, different real-time algorithms can be applied in parallel. If several images are filtered over time (temporal-filtration), image noise can be reduced substantially. More sophisticated methods account for different dose settings and signal levels. Vessel edges can be enhanced by pattern analysis and by contrasting image pixels that are part of a vessel. Motion compensation algorithms decompose the image and detect stationary and moving structures. For example, the results of temporal filtration for moving catheters differ from results of temporal filtration for stationary landmarks, avoiding blurring motion artifacts.

Siemens recently introduced a powerful processing pipeline for Artis systems that allows image quality optimization through advanced processing.

In a first step, the flat panel detector converts the X-ray entrance dose into an electrical signal. Integrated electronics of the detector convert the analog signal into a digital value for each pixel of the detector matrix. The so-called raw data records the image as a whole and is read out as input for the processing pipeline.

In a second step, the raw data is sent to the processing pipeline, where adaptive algorithms are applied to the raw data in parallel to enhance the visualization of the image.

CLEARview: advanced visualization of anatomy even at very low dose

The CLEARview algorithm (Figure 9) applies a dose-adaptive noise reduction functionality to the raw data which is read from the detector. The noise filter settings are optimized to the actual dose. The system decomposes

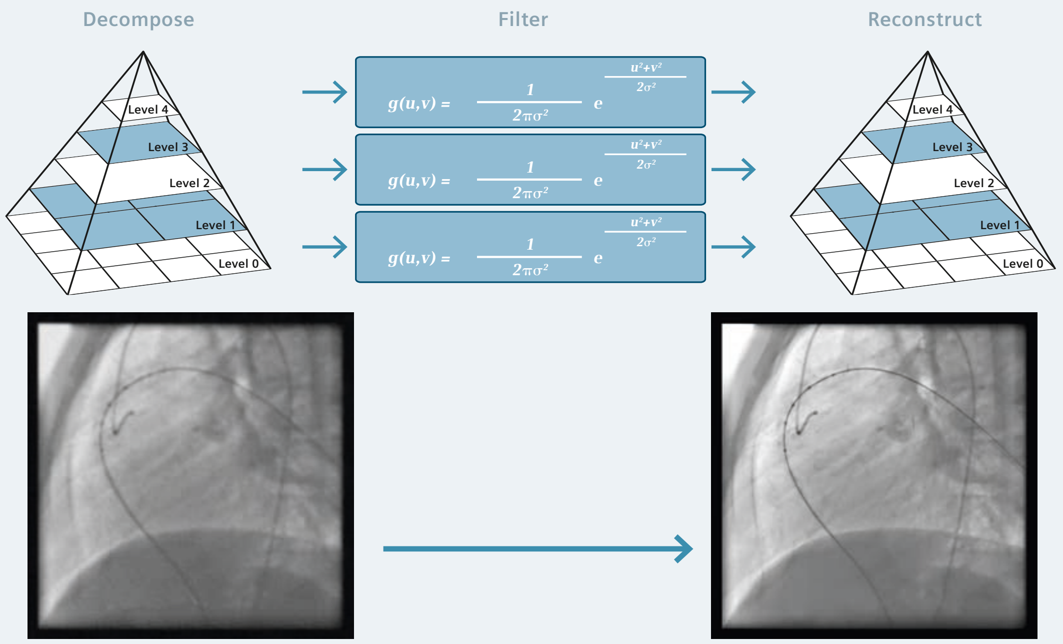


Figure 9: The CLEARview algorithm decomposes the original input image into several layers (based on Gaussian and Laplacian pyramids) and improves the image quality by increasing contrast, especially in low-dose images.

the original input image into several layers, the so-called sub-images, bands or levels. The decomposing is based on Gaussian and Laplacian pyramids (4). The sub-images are filtered individually with the same filter structure in parallel. The basic idea behind optimized filtering is to evaluate every image pixel if it contains a real signal or just noise. The pixels containing only noise will be smoothened; those containing both image information and noise will be smoothened less. The filter settings are also optimized for the detector entrance dose. After filtering, the sub-images are reconstructed and transferred to the next processing step. As a result, the background noise – especially in low-dose images – is significantly reduced.

CLEARvessel: advanced visualization of vessel edges

The CLEARvessel algorithm (Figure 10) significantly enhances the visibility of vessel edges with a smooth background. It analyzes every pixel of the image and combines it with the values of the neighboring pixels in order to enhance only the pixel value within the vessel. Advanced processing steps are applied to analyze the input image for structures, especially vessels. Based on this analysis, the spatial noise reduction is applied locally. With conventional edge enhancement, the image will appear noisy in the areas outside the vessel. CLEARvessel increases the sharpness of vessel edges without increasing the noise in the background.

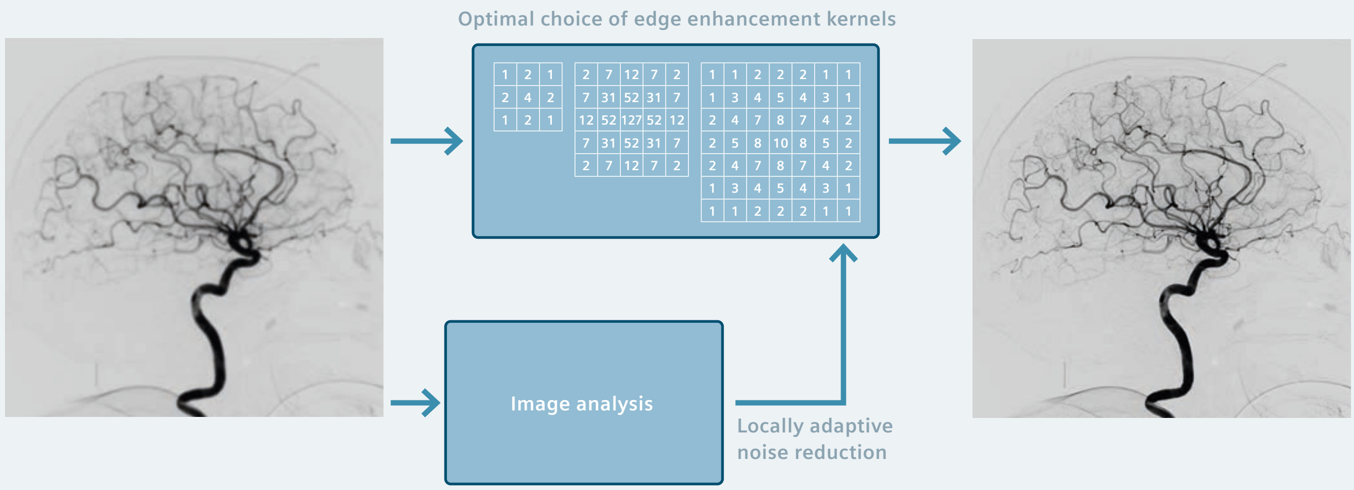


Figure 10: CLEARvessel: The diagram shows the steps for enhancing the visualization of the vessel edges. Depending on the character of the raw images, adaptive spatial filtering increases the sharpness of vessel edges without increasing noise in the background.

CLEARmotion: advanced visualization of moving structures

The algorithm is capable of detecting small moving objects, especially guide wires or fine vessels, and enhances the visibility of the structure (Figure 11). A dedicated multiscale inter-frame filter applies motion-detector-based temporal filtering in every decomposed sub-image and compares the current image with recent images for motion detection. The system adjusts the degree of temporal filtration, separately for each pixel. Blurring caused by motion can thus be efficiently reduced. As a result, moving objects like fine vessels and guide wires can clearly be visualized without motion blurring artifacts.

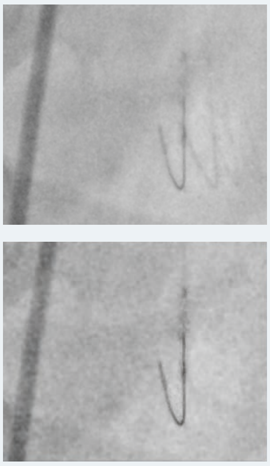


Figure 11: CLEARmotion reduces potential motion-blurring artifacts.

CLEARcontrol: optimized brightness, contrast, and spatial resolution throughout the entire image

The histogram-based dose measuring field with the new CLEARcontrol covers the whole image rather than only parts of it. This allows a more homogenous image with less overexposed or underexposed areas (Figure 12). Also, the object of interest – whether in the periphery or in the center – will always have the right exposure and corresponding optimal image quality.

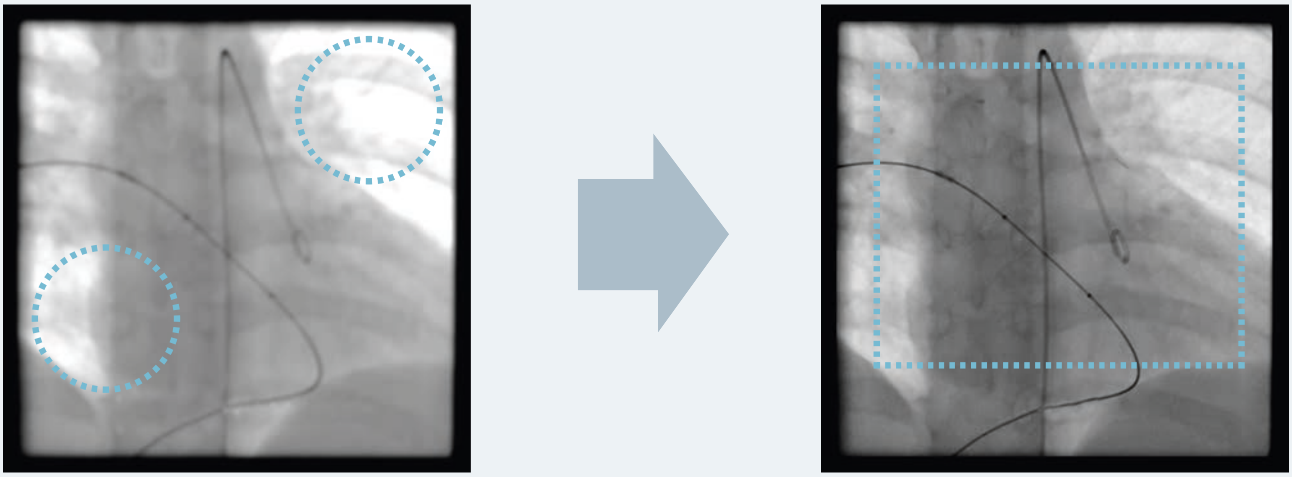
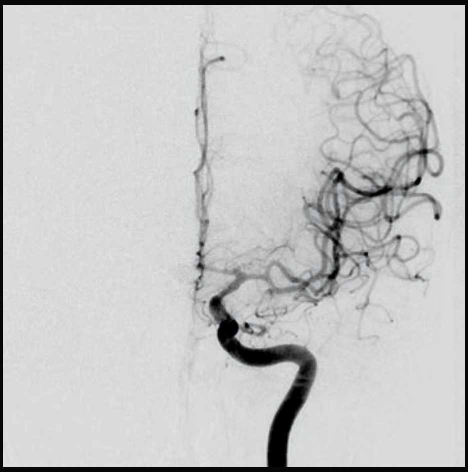


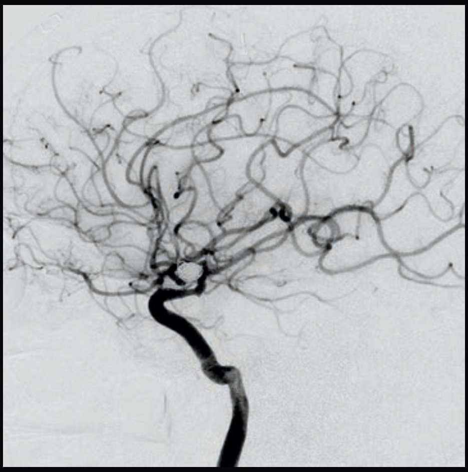
Figure 12: CLEARcontrol optimizes penetration, brightness and contrast throughout the whole image due to the extended histogram-based dose measuring field.

Low-dose Image Gallery[5]

572 nGy/frame @ 32 cm FoV

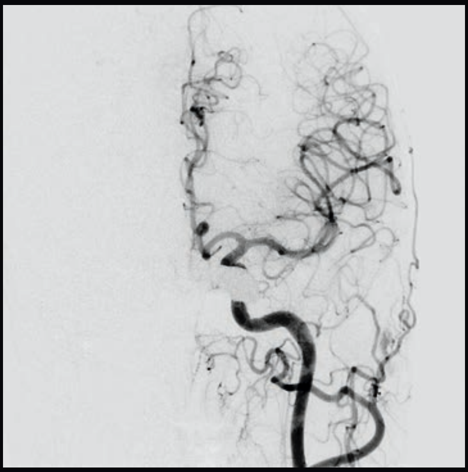


515 nGy/frame @ 32 cm FoV

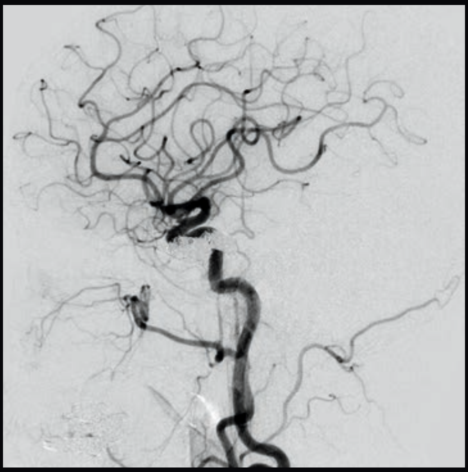


Anterior communicating artery aneurysm after treatment. Control DSAs.
Courtesy of University of Michigan Hospital. System: Artis zee

530 nGy/frame @ 32 cm FoV

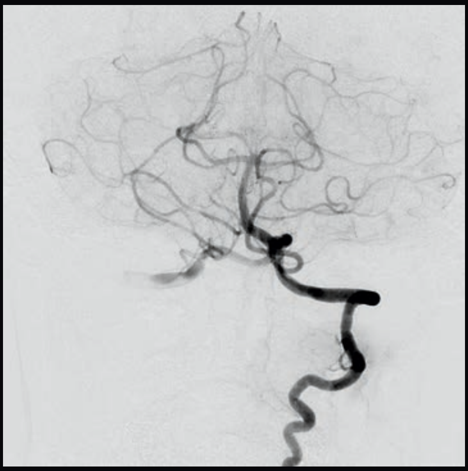


351 nGy/frame @ 42 cm FoV

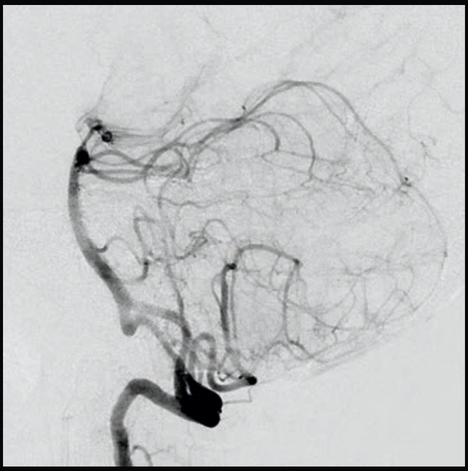


Cavernous carotid aneurysm after treatment. The aneurysm was coiled and control DSAs were done.
Courtesy of University of Michigan Hospital. System: Artis zee

504 nGy/frame @ 32 cm FoV



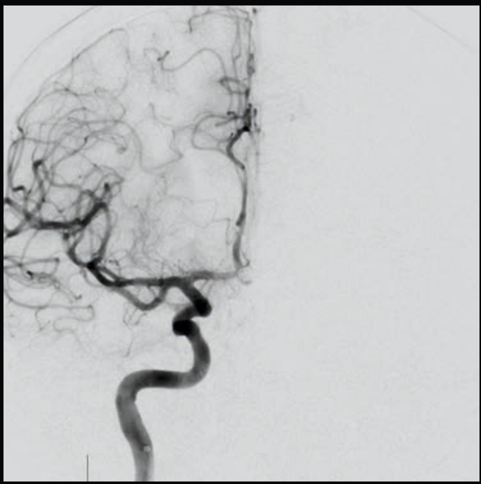
545 nGy/frame @ 32 cm FoV



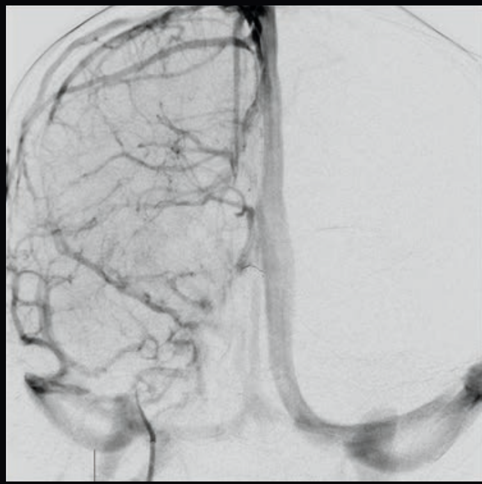
Towne's view and lateral vertebral DSA showing the vertebral, basilar, and posterior cerebral arteries.
Courtesy of University of Michigan Hospital. System: Artis zee

[5] The dose values given in the Image Gallery are detector entrance dose values.

340 nGy/frame @ 32 cm FoV

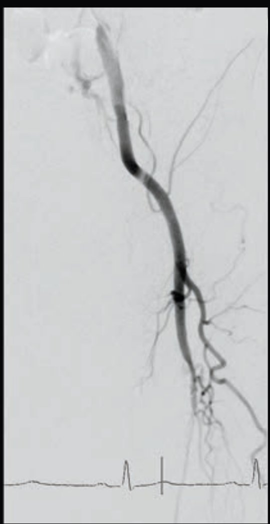


340 nGy/frame @ 32 cm FoV



Control DSA after anterior communicating artery aneurysm coiling showing arterial and venous phases.
Courtesy of Magdeburg University. System: Artis Q

425 nGy/frame @ 48 cm FoV

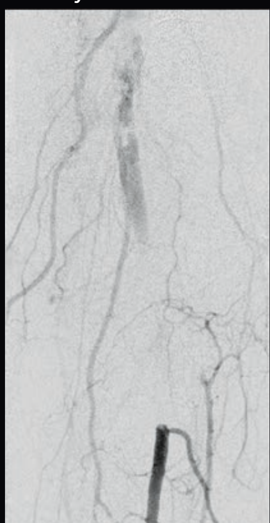


390 nGy/frame @ 48 cm FoV

Left external iliac and femoral DSA showing occlusion of the left superficial femoral artery. Courtesy of MHH. System: Artis Q

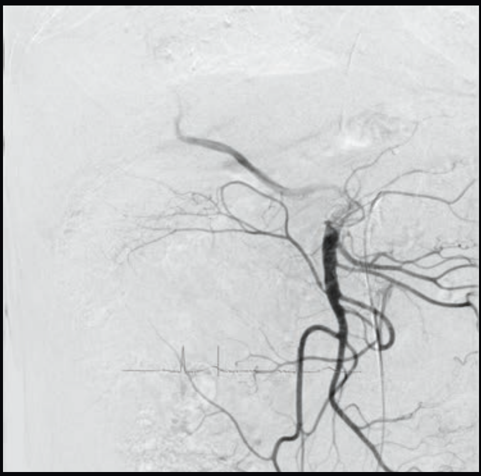
534 nGy/frame @ 32 cm FoV

534 nGy/frame @ 32 cm FoV



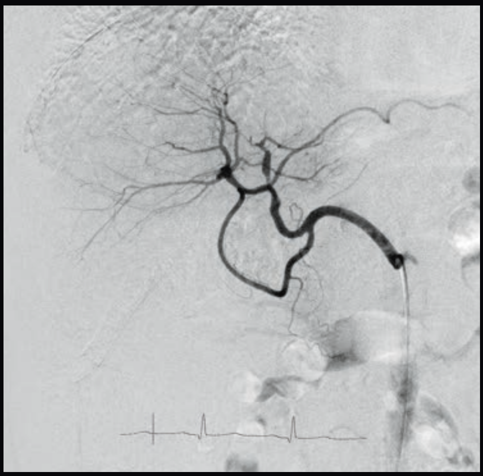
Filling of the popliteal artery and femoral artery through collaterals.
Courtesy of MHH. System: Artis Q

256 nGy/frame @ 48 cm FoV



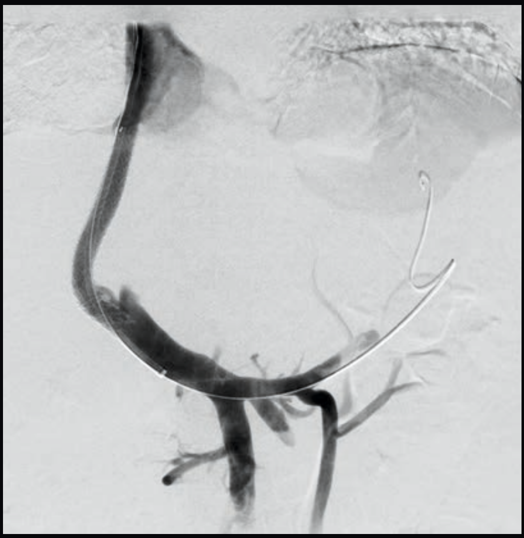
DSA of the superior mesenteric artery.
Courtesy of MHH. System: Artis Q

247 nGy/frame @ 42 cm FoV



DSA of the common hepatic artery.
Courtesy of MHH. System: Artis Q

370 nGy/frame @ 48 cm FoV



Anteroposterior portogram after a successful TIPS (Transjugular Intrahepatic Portosystemic Shunt) showing the stent and the portal vein. Courtesy of MHH. System: Artis Q

340 nGy/frame @ 42 cm FoV

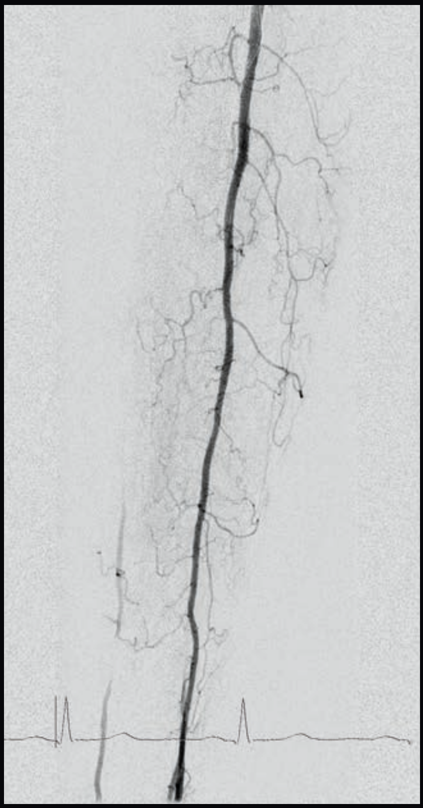
DSA of the left pulmonary artery before embolization.
Courtesy of St. James Hospital. System: Artis zee

MHH = Medizinische Hochschule Hannover

368 nGy/frame @ 42 cm FoV

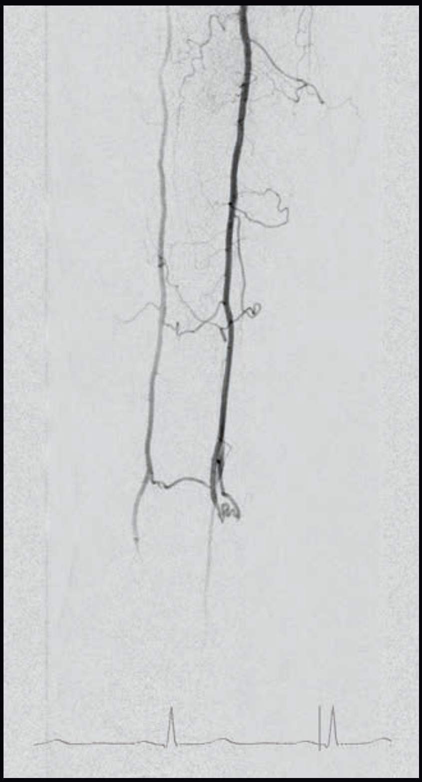
DSA of the femoral artery.
Courtesy of MHH. System: Artis Q

368 nGy/frame @ 42 cm FoV



DSA of the femoral and popliteal arteries.
Courtesy of MHH. System: Artis Q

400 nGy/frame @ 42 cm FoV



DSA of the arteries below the knee.
Courtesy of MHH. System: Artis Q

~ 360 nGy/frame @ 42 cm FoV

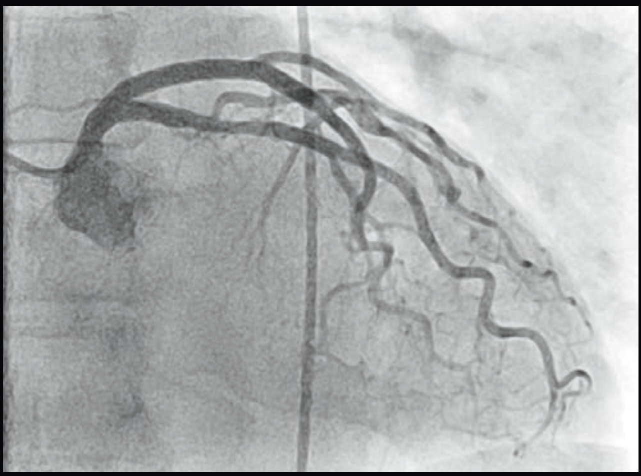
DSA of the iliac arteries before uterine fibroid embolization.
Courtesy of St. James Hospital. System: Artis zee

MHH = Medizinische Hochschule Hannover

350 nGy/frame @ 42 cm FoV

DSA of the left renal artery.
Courtesy of St. James Hospital. System: Artis zee

~ 80 nGy/frame @ 20 cm FoV

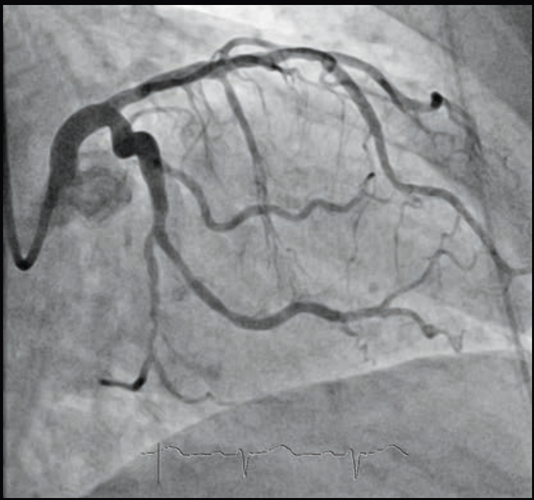


Left coronary angiography.
Courtesy of Klinik Fränkische Schweiz. System: Artis zee

~ 80 nGy/frame @ 20 cm FoV

Right coronary angiography.
Courtesy of Klinik Fränkische Schweiz. System: Artis zee

118 nGy/frame @ 20 cm FoV



Left coronary angiography.
Courtesy of Klinikum Darmstadt. System: Artis zee

Intelligent fluoroscopy with CARE+CLEAR

Fluoroscopy time can be minimized with judicious use of intermittent fluoroscopy and last image hold (LIH). Fluoroscopy is only needed to observe motion or to guide positioning of devices within the body. LIH images and fluoroscopy loops usually are sufficient for intraprocedural review purposes and do not expose the patient to additional radiation (5).

Low-dose fluoroscopy reduces the radiation exposure during fluoroscopy. Artis systems offer different fluoroscopy modes which represent different dose levels. Switching between these different modes – e.g. from "Fluoro high" to "Fluoro medium" or "Fluoro low" – can be done at the table side or in the control room.

CAREfilter during fluoroscopy contributes to low-dose by beam hardening (see page 4).

CAREposition graphically displays the exposed field in the current image on the monitor, based on the LIH. When the patient table is panned, the center of the new field of view is displayed on the current image. The field of view can thus be repositioned without applying any additional radiation exposure through fluoroscopy.

CAREprofile allows to position the collimators and semi-transparent wedge filters without requiring radiation. When the user moves the collimator blades, their actual position is shown as a graphical representation in a previously acquired image which is usually the last image of the previous scene. This enables the user to adjust the filters to the desired positions without any additional radiation. These adjustments are then applied to the subsequent image acquisition. Without this function, the user would have to initiate fluoroscopy to adjust the collimators.

CAREvision uses pulsed fluoroscopy and has the greatest potential for maintaining patient radiation exposure at low levels (5). Siemens systems offer pulse rates ranging from 0.5 to 30 pulses per second and the dose per pulse does not change when the pulse rate is reduced (Figures 13 and 14). The flexibility to change between different pulse rates in small steps with Artis systems increases the flexibility of the user, but at the same time prevents unnecessary dose increases. For example, 7.5 p/s can be sufficient during PCI (percutaneous coronary interventions) and stenting, but if the user decides to increase the pulse rate, he can move from 7.5 p/s to 10 p/s instead of going directly to 15 p/s and thereby significantly save dose.

Effect of pulse rate on patient entrance dose

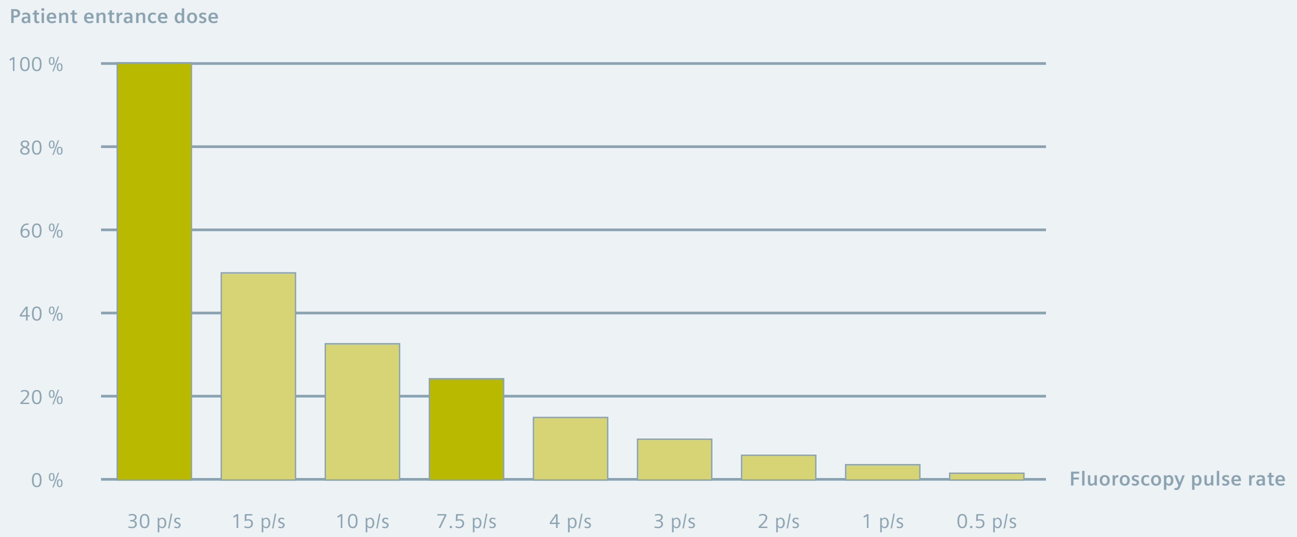
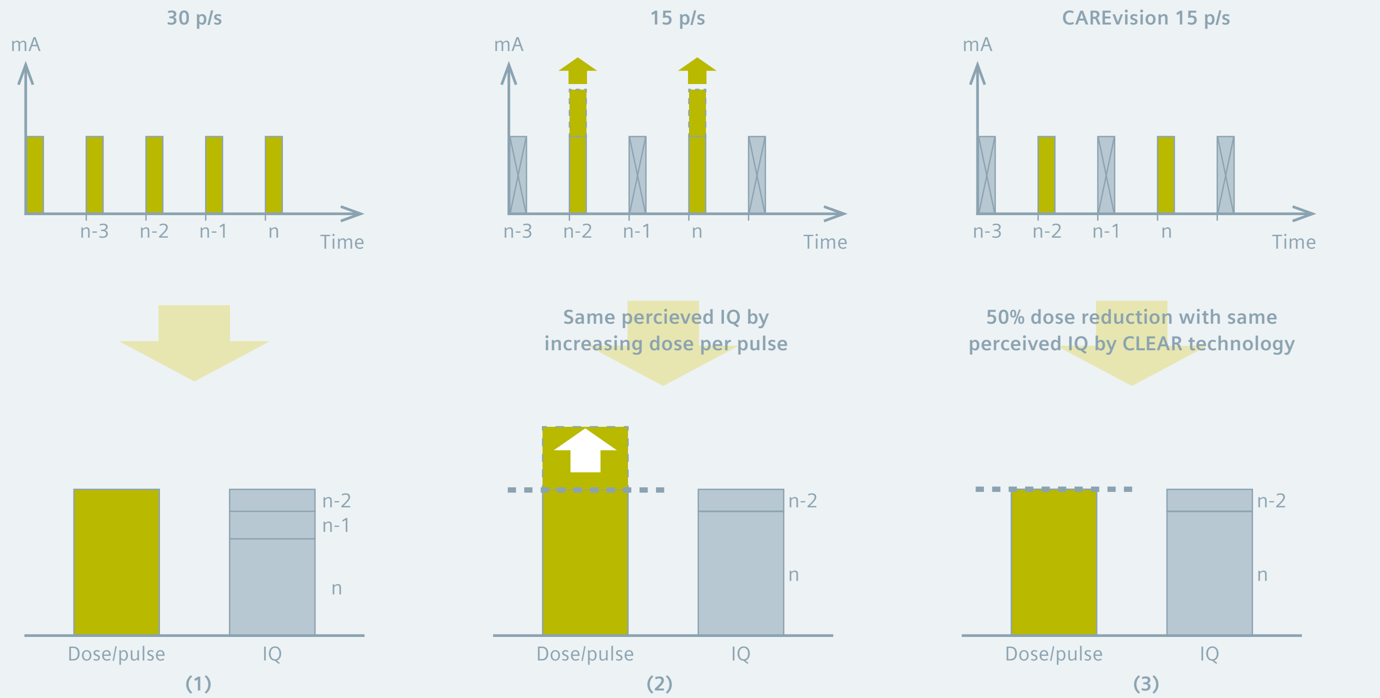


Figure 13: CAREvision provides variable fluoro pulse rates. The pulse frequency of the Artis system can be adapted according to the clinical need: from 30 pulses per second (p/s) in various steps, down to 0.5 p/s. This is the easiest way to reduce exposure to the patient. For example, a reduction from 30 p/s to 7.5 p/s at 70 kV results in a dose saving of 75%[6].

[6] Product dose reduction claims for Artis Q/Q.zen



Using e.g. 30 p/s, the image quality impression contains the whole frame n, some parts of frame n-1, and small parts of n-2 (see gray bar). The dose per pulse is identical.

Reducing the pulses per second means less frames and therefore losing perceived image quality. When reducing the frame rate, e.g. from 30 p/s to 15 p/s, frame n-1 is no longer available. A typical measure to compensate the drop in image quality is to increase the dose per frame by a certain amount.

Siemens approaches this problem differently:

With CAREvision, the perceived image quality can be maintained by the CLEAR technology, which improves the IQ frame by frame.

Every image displayed contains an improved version of frame n and some parts of an improved version of frame n-2. This results in the same image quality as with (1) and (2), but with 50%[6] less dose compared to (1) because the dose per frame can be kept as low as in scenario (1).

Figure 14: Perceived image quality (IQ) indicates the fact that the human visual system always considers parts of previous frames as well. This is illustrated by the upper section of the figure which shows the temporal relationship of the current frame n and the past frames n-1, n-2, etc. CAREvision with CLEAR technology maintains the same image quality even with decreased pulse rate and without increasing the dose per pulse.

CARE+CLEAR is standard with every Artis system.
The CARE+CLEAR features allow users to perform low-dose imaging in all clinical fields and produce diagnostically reliable image quality. The graphs on the following pages (Figures 15, 16, 17, and 18) show the substantial dose reductions that are possible in both cardiac and neuro angiography and fluoroscopy when using low-dose standard organ protocols with advanced exposure control and the automatic copper filter feature. The measurements showing the patient entrance dose were performed with PMMA (Polymethylmethacrylate) phantoms representing different relevant patient thicknesses.

[6] Product dose reduction claims for Artis Q/Q.zen

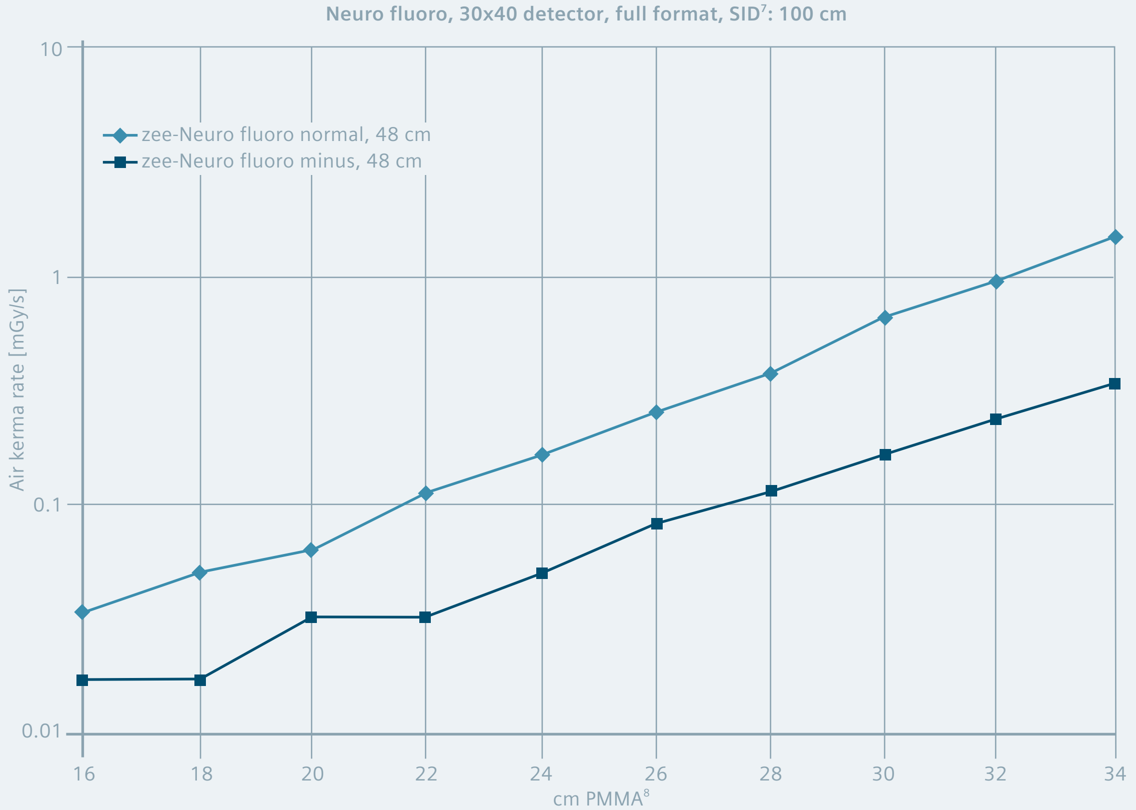


Figure 15: Neuro Fluoro, Artis zee 30x40 Neuro Fluoro air kerma rate comparison at the interventional reference point measured with an SID of 100 cm and full detector format (48 cm). Measurements are based on Siemens standard organ programs with automatic copper pre-filtration.

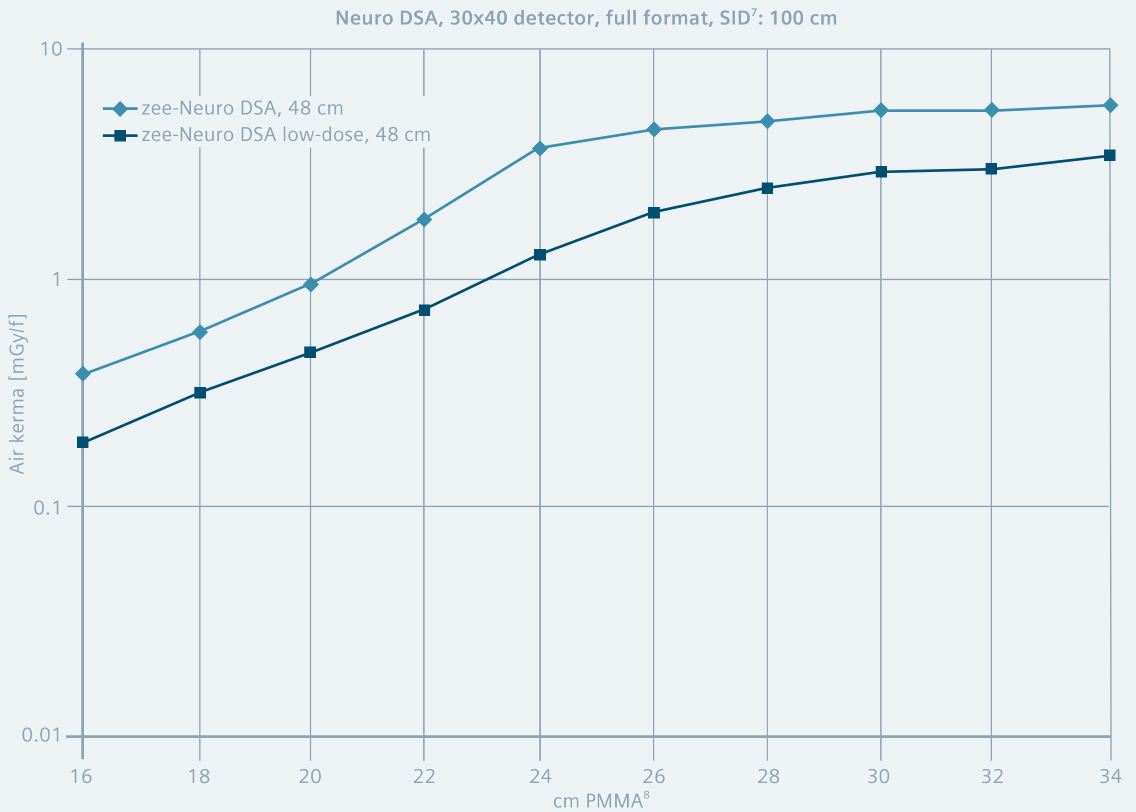


Figure 16: Neuro DSA – Artis zee 30x40 Neuro DSA air kerma comparison in the interventional reference point measured with an SID of 100 cm and full detector format (48 cm). Measurements are based on Siemens standard organ programs with automatic copper pre-filtration.

[7] SID = source to image distance
[8] Polymethylmethacrylate

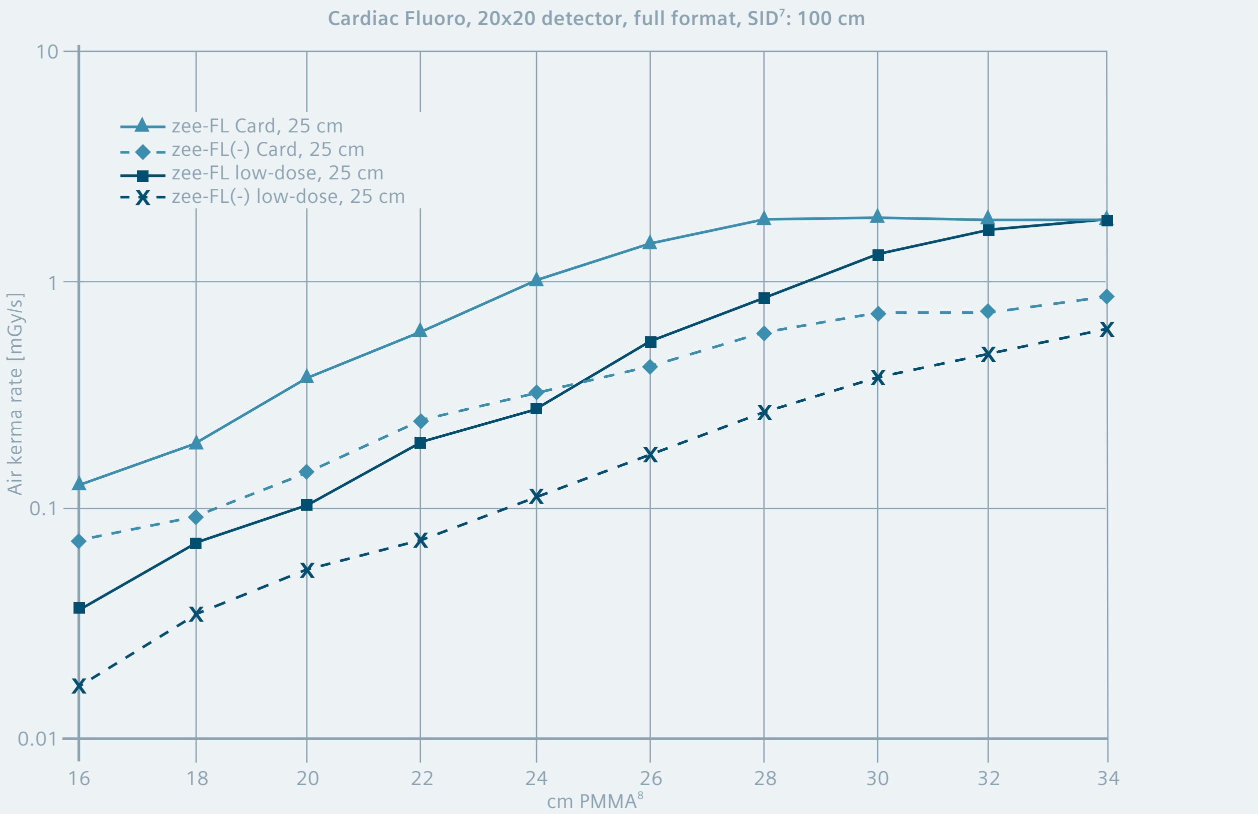


Figure 17: Cardiac Fluoro, Artis zee 20x20 Cardiac Fluoro air kerma rate comparison in the interventional reference point measured with an SID of 100 cm and full detector format (25 cm). Measurements are based on Siemens standard organ programs with automatic copper pre-filtration.

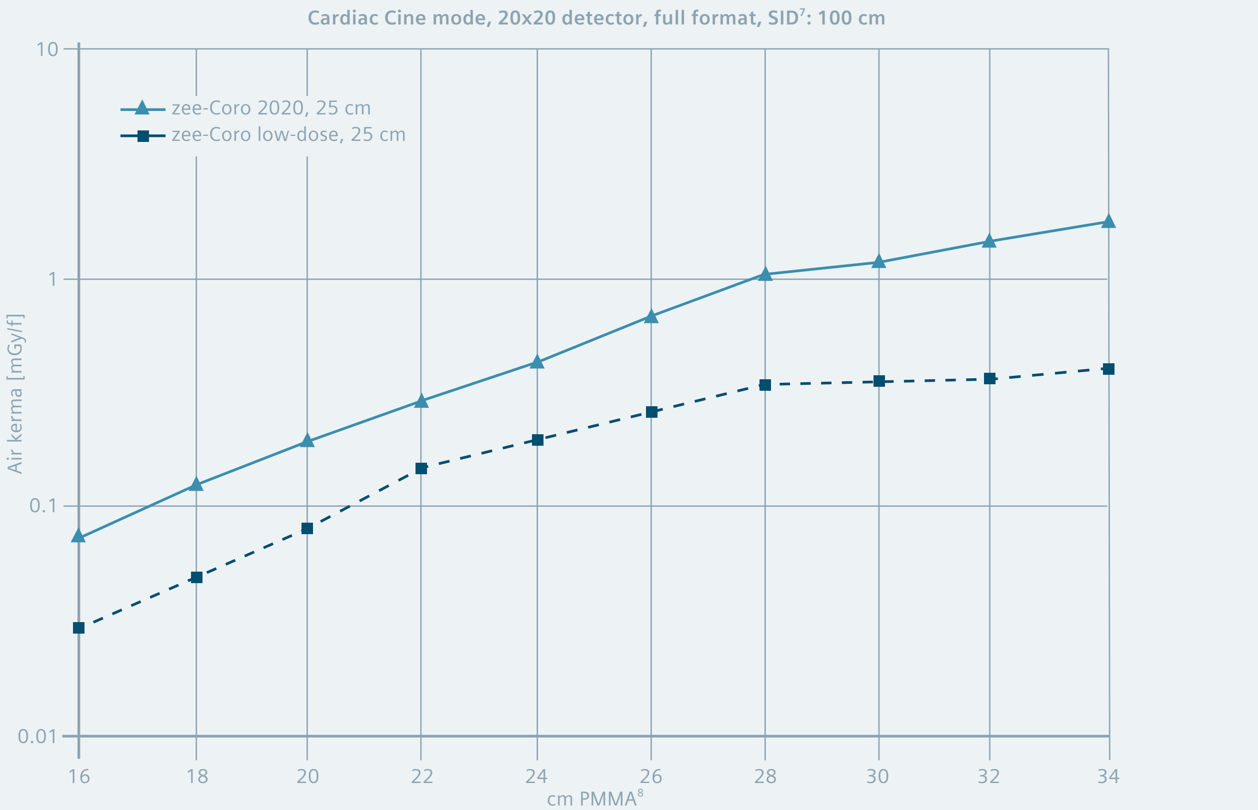


Figure 18: Cardiac Cine mode – Artis zee 20x20 Cardiac Cine mode air kerma comparison in the interventional reference point measured with an SID of 100 cm and full detector format (25 cm). Measurements are based on Siemens standard organ programs with automatic copper pre-filtration.

[7] SID = source to image distance
[8] Polymethylmethacrylate

Dose monitoring and reporting

Monitoring

Monitoring the patient dose is another element to control radiation exposure. The Artis systems are equipped to monitor patient dose in various ways. During the patient examination, the dose values are displayed on the image monitors as well as in the examination room and in the control room. When radiation is off, the dose area product (DAP) and the accumulated dose at the interventional reference point (IRP) are displayed. When radiation is on, the DAP (Figure 19) and the dose rate at the IRP are displayed.

mGy	A: 123	Displayed when the footswitch is not pressed: Dose = 123 mGy DAP = 567.8 µGy m^2
µGy m²	A: 567.8	
mGy/min	A: 321	Displayed when the footswitch is pressed: Dose = 321 mGy/min DAP = 567.8 µGy m^2
µGy m²	A: 567.8	

Figure 19: Dose display on monitors

CAREguard (Figure 20) is an effective way to control the patient entrance dose. Three dose threshold values (low, medium, and high) can be defined. If the accumulated patient entrance dose exceeds a defined threshold:

1. An audible warning is given
2. A dose indicator on the live display flashes
3. A warning pop-up is displayed at the ECC/touchscreen

Two simple basic techniques, based on dose monitoring, will reduce the peak patient entrance dose. The purpose of these techniques is to reduce the patient entrance dose at any one point on the skin surface by irradiating different portions of the skin at different times during the course of the procedure.

The first technique is dose spreading. It changes the position of the radiation field on the patient's skin using small amounts of gantry angulation, table movement, or both. Spreading the patient entrance dose in this way reduces the peak patient entrance dose, the size of the skin area subjected to the peak patient entrance dose, and the size of the skin area at highest risk. The second technique is collimation, which is just as important as dose spreading. Even with the dose spreading technique, different irradiated fields can overlap on the skin surface. The overlap area receives a higher dose. Tight collimation may prevent overlap, especially with biplane fluoroscopic units, and markedly improve the effectiveness of dose spreading techniques (5).

CAREmonitor shows the accumulated peak skin dose according to the current projection in the form of a fill indicator on the live monitor. Any change to the C-arm, table, SID, zoom, or collimator prompts the system to automatically update the calculation, even when the radiation is off (Figure 21).

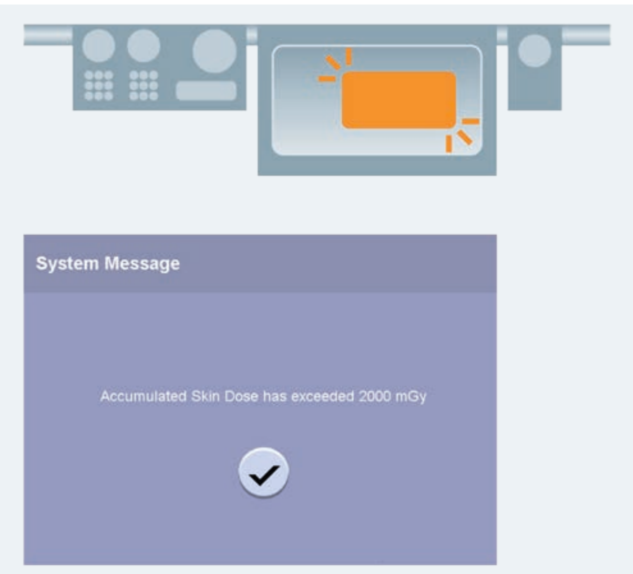


Figure 20: CAREguard

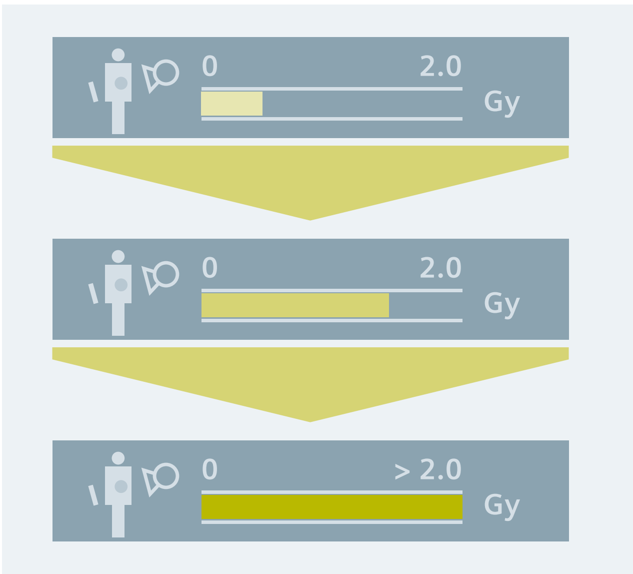


Figure 21: CAREmonitor shows accumulated skin dose in real time.

Reporting

After a patient has been examined, an exam protocol is stored together with the acquired images, containing the complete dose information for each run. At the end of the protocol, the dose information is listed: number of exposures, total fluoro time, total dose area product, and total dose at IRP. These values are given separately per plane.

The examination protocol can be sent to a PACS system and printed as an image. It can also be stored and sent as a DICOM structured report for further evaluation. CAREreport contains all patient demographics, procedure, X-ray, and dose information. This information can be filtered for further processing, such as dose analysis.

Conclusion

Low dose has been a Siemens priority since 1994, making us a pioneer in this area. Within the last 10 years, the requested detector entrance dose for low-dose imaging has been reduced by up to 85%. This document presents some of the key technologies of Artis systems that reduce radiation dose to ultra-low levels, leading the industry standards: Advanced Exposure Control with CARE, state-of-the-art real-time processing CLEAR and dose-reduction features (CARE), new and advanced fluoroscopy techniques, and dose monitoring. Artis systems have a clear advantage with AEC which can automatically adjust five parameters dynamically during the procedure. Especially CAREfilter, which adapts to the patient thickness also due to changes based on the angle of a projection during the exam, has a substantial impact on the reduction of patient dose. Today it is possible to perform a head DSA examination with 42 cm FoV and with detector entrance dose of ~300 nGy/frame. The image outcome after such an ultra-low dose level is improved with the CLEAR real-time processing algorithms to better support the ALARA principle in interventional procedures. Dose reduction and image processing techniques mentioned in this document are included in the CARE+CLEAR package with all Artis systems at no additional cost.

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(4) Adelson, E. H., C. H. Anderson, J. R. Bergen, P. J. Burt, J. M. Ogden. "Pyramid methods in image processing." RCA Engineer 29-6, (Nov/Dec 1984).

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