

The Brilliance iCT and DoseWise strategies—

Simplification of dose management with optimized image quality

Abstract

Fulfilling the demand for effective diagnostic and therapeutic information has led to a steady increase in the use of CT. With this trend, CT departments strive to scan with the ALARA^a principle; however, its practice varies significantly among sites and scanners servicing an ever-widening range of clinical indications and patient populations.

Strategies for simplifying CT dose management are described that combine advances in the Brilliance iCT platform with DoseWise programs and collaborative partnerships. Multiple components of the Brilliance iCT imaging chain have been scaled up to increase volume imaging speed, dose efficiency, and image quality, thereby enabling opportunities for lower dose scan protocols. Eight seamlessly integrated protocol-driven and patient-adaptive dose reduction technologies are described that automatically use the quantity and quality of radiation where and when needed, leading to dose reductions of up to 80% over previous methods.

Results from clinical collaborations show how intelligent advances of the Brilliance iCT operate synergistically, along with DoseWise training programs, to provide comprehensive and application-specific advantages for low dose and image quality (IQ) optimization. Dose reductions are reviewed for routine brain, chest, and abdominal scans including pediatric protocols (aligned with or below Image Gently^b reduction factors). ALARA practices are simplified for emerging and challenging applications including cardiac imaging (doses reduced by as much as 80%), brain perfusion, and CT colonography (estimated doses 0.7-0.9 mSv²).

A new era of expanding Multi-Detector CT (MDCT) will be fueled not only by increasing clinical benefits, but also by easily lowering dose to levels not previously possible for broader patient populations. Together in close partnership with the CT community, the Brilliance CT scanners and the DoseWise strategies embody this vision and facilitate improved patient care.

a Patient radiation dosage "As Low As Reasonably Achievable"

b Image Gently, The Alliance for Radiation Safety in Pediatric Imaging

1. Introduction

Physicians have ranked CT atop the list of innovations that have improved patient care³. While meeting diagnostic and therapeutic imaging objectives for expanding services, CT departments and centers strive to routinely scan with patient radiation doses ALARA; however, techniques for practicing ALARA can vary significantly by clinical indication and patient population⁴. Surveys have

shown significant variations between sites and scanners including wide ranges of radiation dose for the same scan indication⁵, utilization of adult scan protocols for pediatrics⁶, and opportunities to increase awareness of CT dose estimates⁷.

Philips DoseWise Strategies for CT: Simplifying dose management with optimized IQ

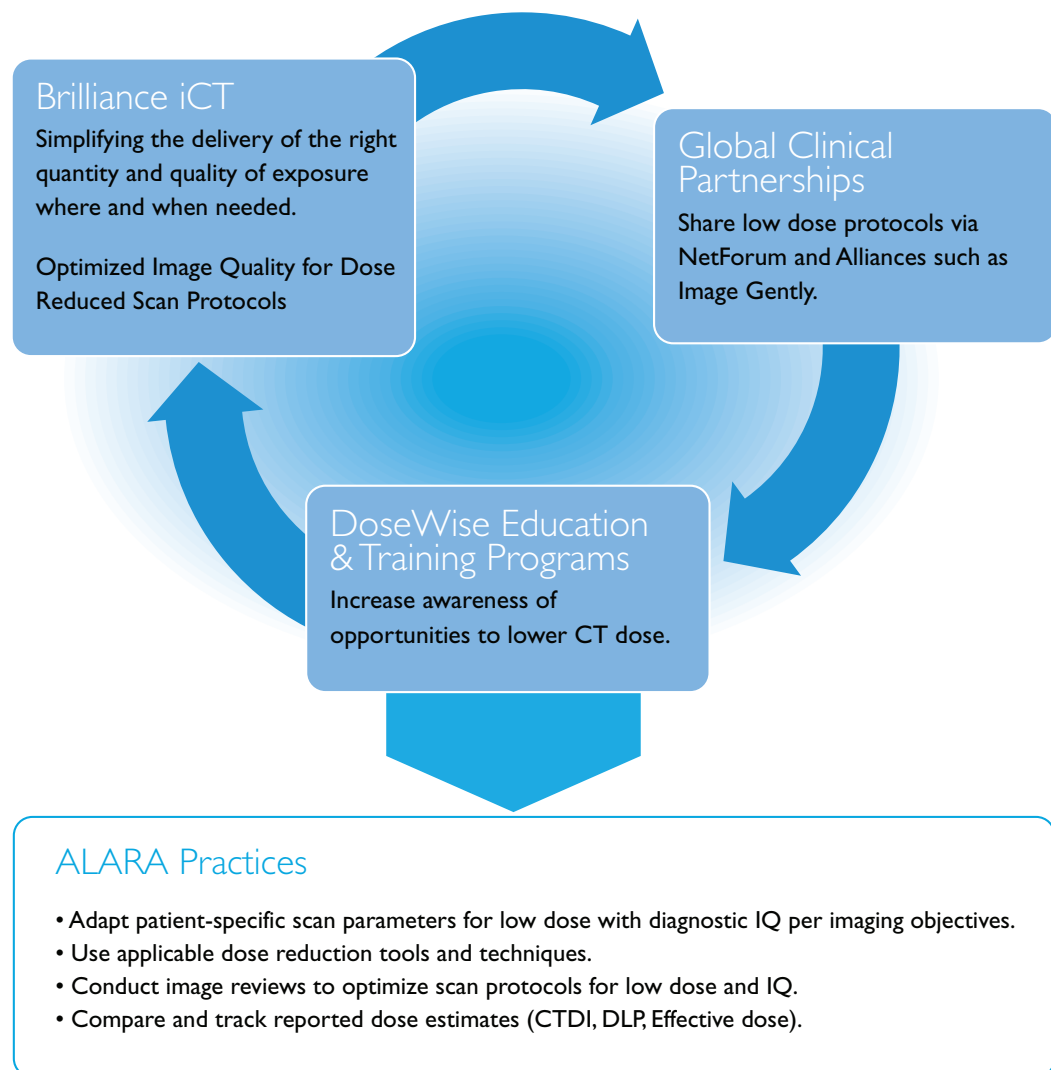


Figure 1: Summary of Philips Brilliance iCT and DoseWise strategies that simplify ALARA practices.

Dose management is simplified with Philips Healthcare's DoseWise philosophy⁸ and the advances of the Brilliance iCT platform. Each stage of the Brilliance iCT's imaging chain—from tube to detector—has been enhanced with innovative volume imaging technology and integrated with new dose reduction and reporting tools. The resulting image quality and dose efficiency improvements can help meet imaging objectives with doses ALARA (Section 2). Dose reduction tools are integrated with each stage to automatically control the quantity and quality of radiation where and when needed (Section 3). Figure 1 summarizes how these imaging performance enhancements are synergistically combined with ALARA practices, DoseWise training programs, global networks including the Philips NetForum clinical community⁹, and alliances such as Image Gently^{6,10}. These strategies and advances can provide robust and application-specific advantages to simplify dose management for routine, as well as an increasing number of emerging and challenging examinations encompassing broader patient populations (Section 5).

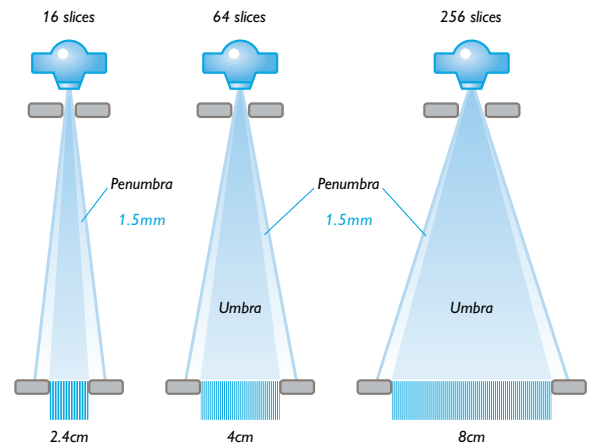


Figure 2: Larger detector coverage provides more dose efficiency since overbeaming is reduced. The Z-axis dose efficiency with 8cm coverage is 3.4% and 7.5% higher than with 4cm and 2.4cm of coverage, respectively

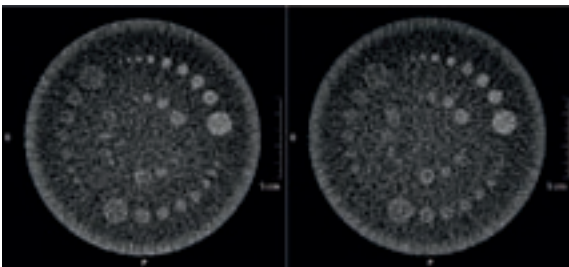
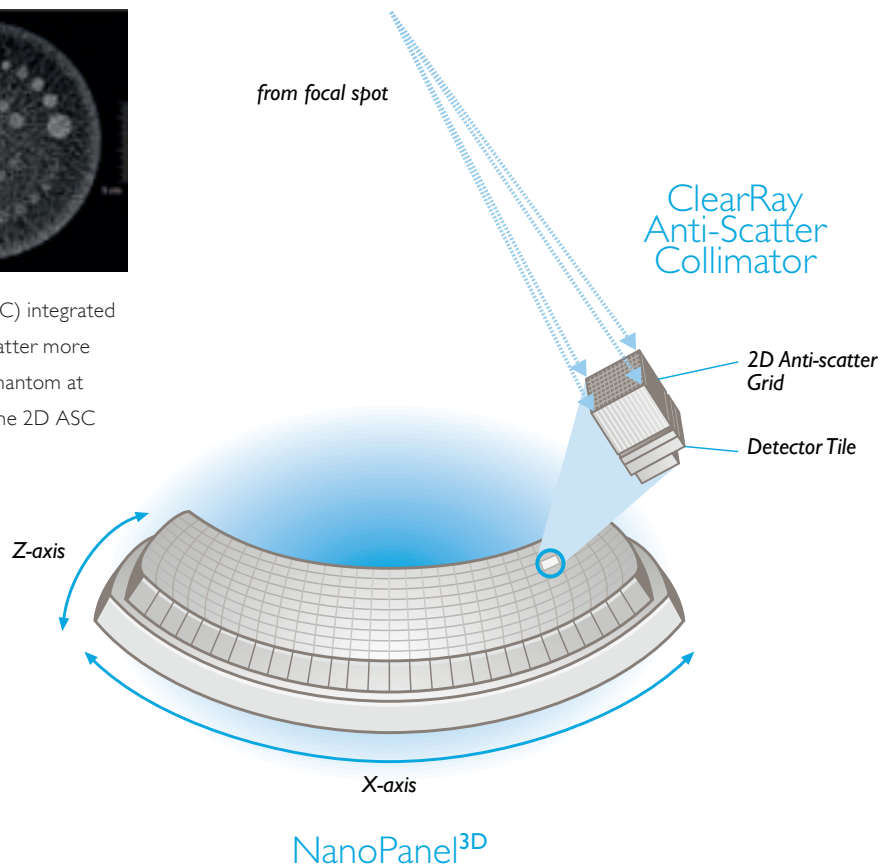


Figure 3: ClearRay 2D anti-scatter collimators (ASC) integrated on NanoPanel^{3D} detector tiles decrease volume scatter more effectively than the 1D ASC. Scans of a Catphan phantom at the same dose show improved low contrast with the 2D ASC (above, left) compared with the 1D ASC (right).



2. Brilliance iCT: scaling up Essence technology for image quality and dose efficiency

A high-performing volume CT imaging chain with inherent image quality (IQ) and dose efficiency can enable the optimization and routine use of lower dose scan protocols. To accomplish this, designers of the Brilliance CT scanners have invested decades of research and development, with the company wide DoseWise philosophy, resulting in a highly scalable platform, referred to as Essence technology¹¹. Intelligent advances in Essence technology for the Brilliance iCT provide a new standard of fast volume imaging performance with inherent IQ and dose efficiency, including:

- **Wider detector coverage:** The 8cm coverage of the Brilliance iCT's NanoPanel^{3D} detector reduces overbeaming by increasing Z-axis dose efficiency to 96.4 % from 93.0% at 4cm coverage, as shown in Figure 2.
- **2D Anti-scatter collimation (ASC):** The NanoPanel^{3D} detector is spherically shaped so its ClearRay 2D anti-scatter grids (Figures 3 and 4) can be focused for true 3D cone-beam geometry. The resulting scatter reduction can improve low contrast resolution (LC) and uniformity by reducing the scatter-to-primary ratio (SPR) to 6%¹² from 18% for the 1D ASC. A Catphan phantom was scanned to compare low contrast with 2D and 1D ASC at the same dose. Additional LC detail can be seen with the 2D ASC (Figure 3, left) compared with the 1D ASC (right).
- **Fast rotation speed:** The new AirGlide gantry uses a frictionless system—as an alternative to ball bearings— that enables rotation speeds of 0.27 seconds resulting in a substantial improvement in temporal resolution. This speed helps minimize motion artifacts for challenging examinations such as Step & Shoot Cardiac imaging with higher heart rates or when scanning restless children.

These dose efficiency and IQ improvements, such as a reduction in scatter and motion artifact, and others from Essence technology summarized in Table 1 of the Appendix, can provide opportunities to meet imaging objectives with scan protocols adapted for doses ALARA. Conversely, an incomplete imaging solution that may include wider coverage or two tubes could lead to trade-offs and unnecessary dose in an attempt to meet contrast and other IQ requirements for many indications and objectives. Advances in Essence technology—integrated with dose reduction tools described in the next section—show that dose and image quality do not need to be difficult trade-offs. They can be easily managed and optimized as shown in Section 5.

3. Brilliance iCT: integrated dose reduction technologies automatically decrease unnecessary exposure

To further simplify dose management, the Brilliance iCT platform has a complete set of advanced dose reduction tools (DRTs) seamlessly integrated with Essence technology. DRTs control the quantity and quality of exposure where and when needed as summarized in the stages of the imaging chain (Figure 4). Tube current modulation techniques (ACS, Z-DOM, D-DOM, Cardiac), beam shaping (SmartShape) and quality filters (IntelliBeam), the helical end-effect collimation (Eclipse), and advanced gating techniques (Step & Shoot Cardiac) are described below in sequence from X-ray source (iMRC tube) to detector (NanoPanel^{3D}) (Figures

5-9). Special pediatric dose saving techniques are then described to show how DRTs are used in concert along with age- and weight-based tube current reduction factors (Figure 10).

The integrated set of dose reduction tools is patient-adaptive and protocol-driven to automatically deploy the optimum component configurations for each scan. A number of DRTs, such as the SmartShape wedge (bowtie) filters, are designed to optimize both dose and image quality, while others, such as the Eclipse helical end-effect collimator, lower exposure without affecting IQ.

Brilliance iCT

Simplify the delivery of the right **quantity** and **quality** of radiation **where** and **when** needed...

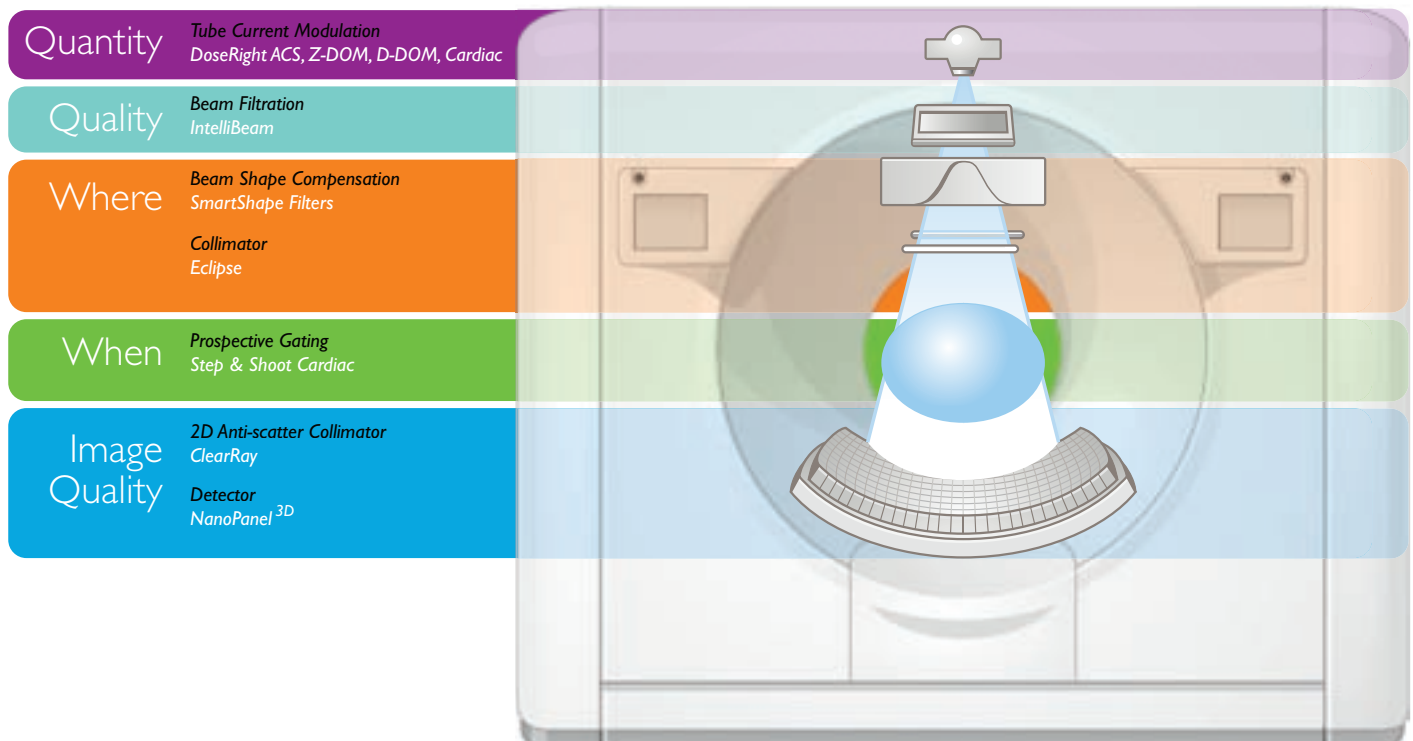


Figure 4: Philips Brilliance iCT platform with Intelligent advances in Essence technology and integrated dose reduction tools

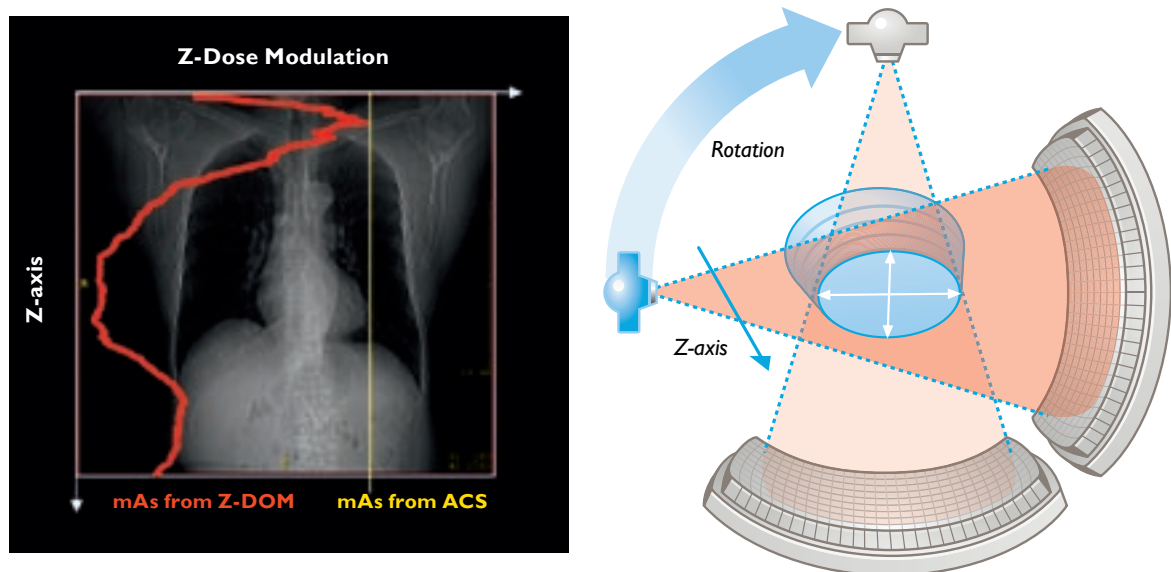


Figure 5: DoseRight dose modulation; Automatic tube current selection (ACS), Z-axis dose modulation (Z-DOM), dynamic angular dose modulation (D-DOM), and Cardiac (ECG triggered DOM)

Automatic current selection (ACS)

If scan parameters were not adapted for the size of the scan region, larger (smaller) patients would receive less (more) dose per kilogram. This is because for a given projection, the center and peripheral region nearest the detector would typically have lower (higher) beam intensity for a larger (smaller) patient due to attenuation along a larger (smaller) diameter. The summative effect with each tube rotation would result in higher (lower) average noise levels for larger (smaller) patients.

ACS automatically suggests tube current settings according to estimated patient diameter in the scan region. A default “reference” tube current corresponding to average patient weight is developed through clinical collaboration for each scan protocol. When planning an examination, the patient’s maximum diameter is estimated from the “Survview.” ACS then uses that maximum diameter to scale the reference tube current to control the dose and noise level by suggesting a higher or lower value for larger or smaller diameters, respectively. If the operator modifies the suggested tube current based on reviews of image quality, a moving average of these adjustments is used to update the reference value.

Performance measurements

ACS was used to investigate 40 patients at two clinical centers using a standard abdominal protocol. With ACS, the image noise level was more uniform for variations in patient size¹³.

Z-axis dose modulation (Z-DOM)

Average X-ray attenuation can vary significantly along the craniocaudal (Z) axis. For example, the chest can have a much lower average attenuation than the abdomen due to air in the lungs. Prior to scanning, a Z-axis profile of the patient’s diameter (red line) can be estimated from the Survview (left). The profile can then be used to modulate the tube current for each table position based on ACS (yellow line). The maximum, average, and minimal tube current levels for Z-DOM are displayed when planning the scan, and the percentage dose reduction is displayed with the reconstructed images.

Performance measurements

In a study of adult abdominal scans, Z-DOM lowered the average tube current by approximately 32% relative to each patient's unmodulated tube current¹³. Z-DOM used with chest scans can reduce dose by up to 50%. In whole body or multi-region examinations such as chest, abdomen, pelvis or head, neck, chest scan protocols, Z-DOM has been seen clinically to lower patient dose by about 20-40%.

Dynamic angular dose modulation (D-DOM)

The X-ray attenuation of the patient can also vary with tube rotation angle. For example, the shoulder region can have a higher attenuation laterally than anteroposteriorly. D-DOM modulates the tube current during helical scans according to changes in patient shape (eccentricity) and tissue attenuation as the tube rotates. For each rotation, projections are processed to determine the maximum and minimum patient diameter (right, Figure 5). The tube current for the next rotation is then modulated between these limits.

Performance measurements

Accounting for angular attenuation variation can result in major dose savings without compromising image quality. Clinical results show that the dose savings are 10-40% for chest or abdomen examinations.

Cardiac ECG Triggered dose modulation for retrospectively gated helical scans

In helical cardiac scans, radiation dose reduction can be achieved by prospectively modulating the tube current using the ECG information. The tube current can be kept at the nominal level (100%) during the targeted cardiac phase of interest and can be reduced to 20% during all other phases of the cardiac cycle.

Performance measurements

Using this approach, dose savings of up to 45% can be achieved without compromising the image quality in the cardiac phase of interest, depending on the heart rate during the acquisition¹⁴.

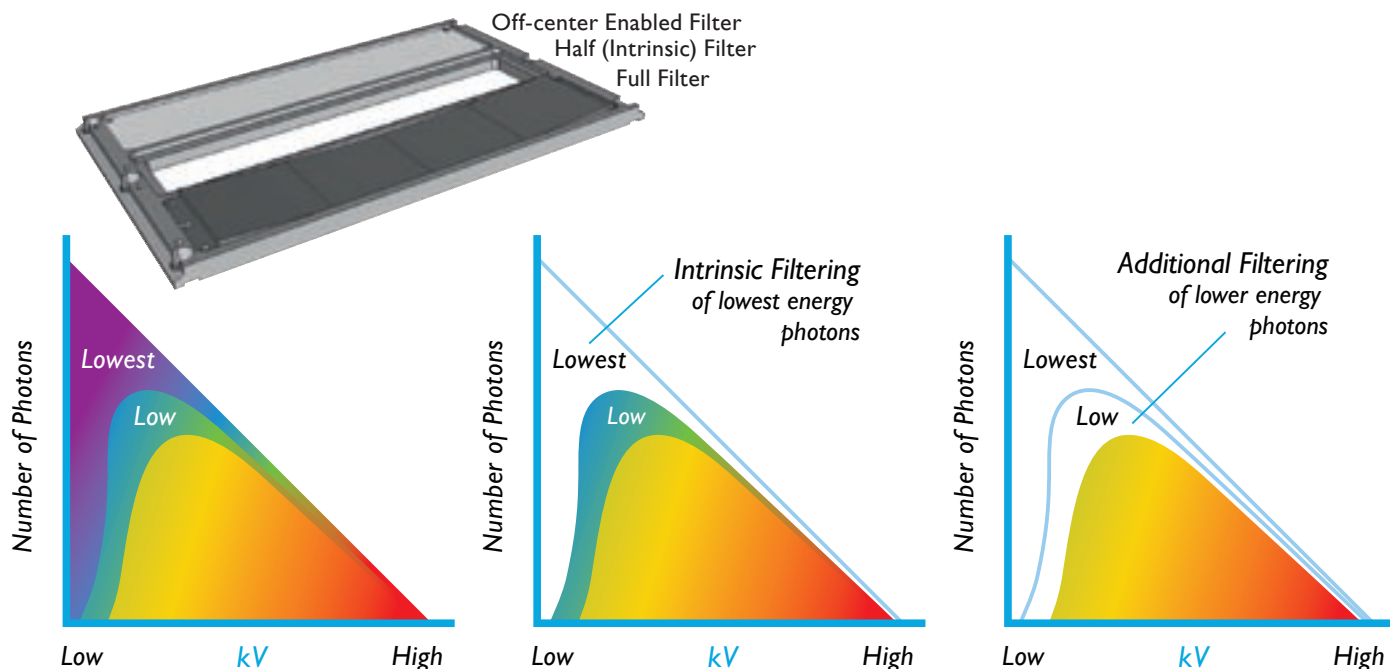


Figure 6: IntelliBeam Filters

For a selected peak kilo-voltage setting (80, 100, 120, and 140 kVp), the low energy content (softness) of X-ray spectrum can affect dose and image quality: a beam that is too “soft” (above, left) can increase skin dose and a beam that is too “hard” (higher “quality”) can decrease contrast detail. On the Brilliance iCT, the beam’s hardness (quality) can be controlled with selectable IntelliBeam filters (filter tray shown above). The filter selection is configured with scan protocols, and is used automatically in combination with SmartShape wedges (right column in the table below) (shown in Figure 7) and the iMRC’s intrinsic filtration to optimize both low contrast resolution and dose.

The filters are designated “full,” (shown on the right) “half,” and “off-center enabled.”^c The half filter is used with infant protocols to enhance low contrast resolution. This helps manage dose in combination with the small wedge and intrinsic filtration (as shown in the table).

Performance measurements

The full IntelliBeam filter used with all adult head and body protocols reduces dose by about 30% at 120kVp and 46% at 80 kVp relative to half filter.

Default scan protocol	Tray position	HVL ^d (mm Al equiv)	Wedge
Adult head & body	Full	8.7	Large
Cardiac	Full	8.7	Medium
Infant	Half	7.4	Small
Trauma	Off-center	7.8	Open

^c A special trauma scan protocol uses a custom filter without a wedge. This protocol is useful when patient centering is either not possible or not a priority.

^d Half-value layer (HVL) is the thickness of material required to decrease the 120 kVp beam intensity by 50%.

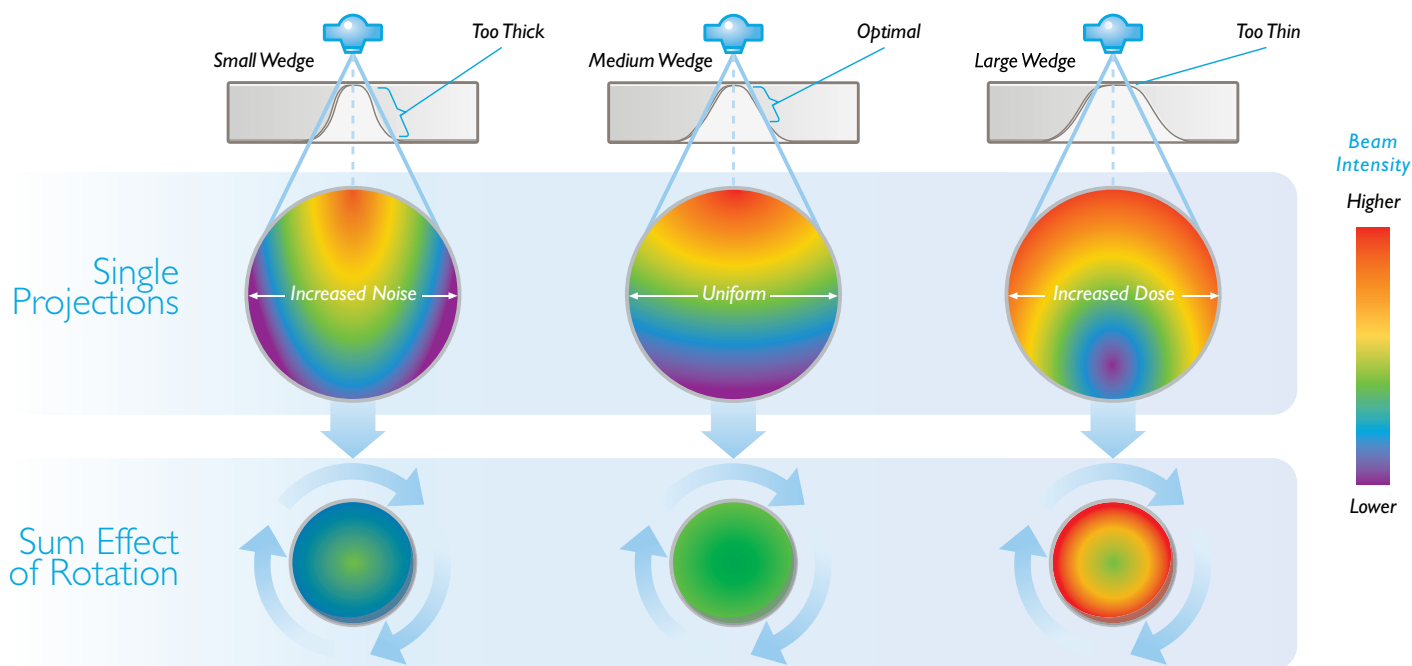


Figure 7: SmartShape wedge (bowtie) filters

Wedges, also known as bowtie filters, can increase both dose efficiency and image quality. This double advantage is achieved by filtering the beam's intensity according to the patient's shape. Each wedge provides more filtering from medial—where the patient thickness is greatest—to lateral, thereby facilitating a uniform dose and noise distribution as the tube rotates (shown above in center column). Three SmartShape wedges are provided: a) small: infants 0-18 months, b) medium: cardiac, and c) large: adult head and body.

A medium size phantom is used in the diagram to illustrate the importance of wedge size. It shows a green shaded beam intensity in the center region for all three wedge sizes. When a large (small) wedge is used on the medium phantom, as shown on the right (left), the wedge's peripheral attenuation thickness is too small (large), the peripheral beam intensity is too high (low), resulting in a higher (lower) peripheral dose. When appropriately sized, the wedge's curvature facilitates a uniform exit beam intensity and image quality throughout the scanned region. They are used in conjunction with the IntelliBeam (Figure 6) filters, and are automatically selected based on the protocol being used.

Performance measurements

Infant wedge: $CTDI_{(vol)}$ is reduced by approximately 14% and 22% as measured with the standard FDA head (16cm) and body (32cm) phantoms, respectively, compared with the large wedge. A dose savings of 10-14% can therefore be estimated for properly centered infant body examinations since the head phantom better approximates infant body size (less than 18 months).

Cardiac wedge: Body $CTDI_{(vol)}$ and $CTDI_{(peripheral)}$ is reduced by approximately 11% and 13%, respectively, relative to the large wedge. These results can be used to estimate a lung dose savings of 11-13% for properly centered cardiac examinations.

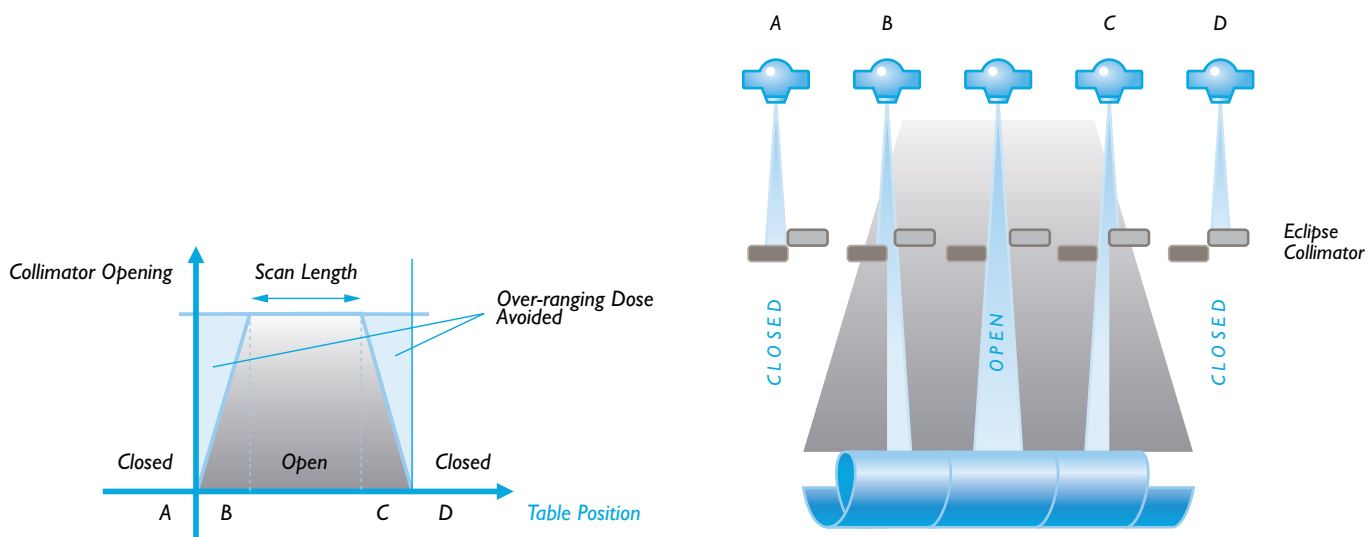


Figure 8: Eclipse (helical end-effect) collimator

Unnecessary, wasted exposure that does not contribute to imaging can occur at the beginning and end of helical scans. The Eclipse collimator—a component of the Brilliance iCT imaging chain that complements wide detector coverage—automatically opens at the beginning and closes at the end of helical acquisitions as shown in the diagram. This dynamic collimator reduces unnecessary exposure without affecting image quality.

Performance measures

DLP^e is reduced by one-half rotation at the start and by one-half rotation at the end of the helix (shown as regions a–b and c–d). Therefore, dose reduction is proportionally higher with wider collimation, when using a larger pitch, and for shorter scan lengths.

The combination of wider detector coverage and dynamic collimation reduces both “over-beaming” and “over-ranging”¹⁵. Dose reductions can be considerable, especially with short length helical scans, such as those used in cardiac, pediatric, and brain exams (discussed in Section 5).

	Typical scan length (cm)	Dose savings on DLP
Pediatric chest	8	33%
Abdomen	32	17%
Head/Brain	16	25%

^e Dose length product = scan length * CTDI

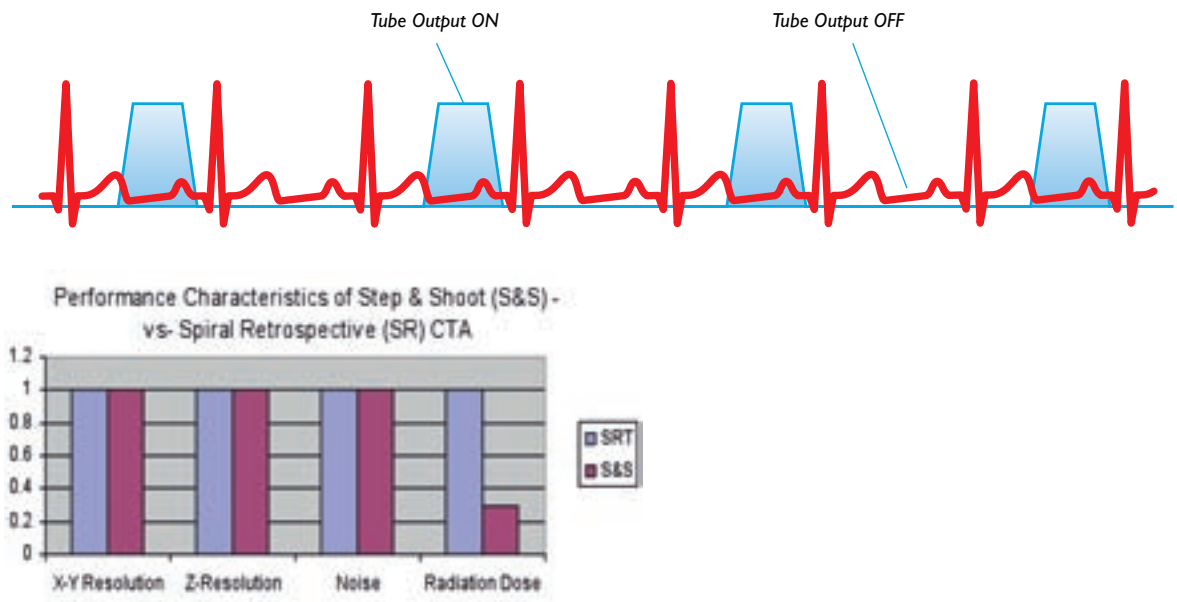


Figure 9: Prospective gating (temporal dose modulation)

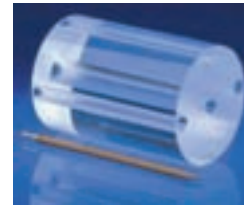
Imaging tissue, or an organ, over multiple physiological phases (e.g., over the cardiac cycle) can provide both anatomical and functional information; however, for many indications it is only necessary to image—and expose—a single phase. The fast, high-resolution, volume imaging enabled by the Brilliance CT platform is complemented by new gating methods. Using these methods, the tube current can be prospectively modulated to image only a desired phase in an axial scanning mode. One such method, Step & Shoot Cardiac, enables prospectively gated axial cardiac scanning during the “quiet” phase of the cardiac cycle. Through the modulation of the tube current and selection of only one phase (above, top), significant dose reduction is made possible (Section 5). Furthermore, larger detector width can be further leveraged by increasing the axial shot coverage for decreasing field of view. This enables larger step lengths with minimum cone beam overlap.

Performance measurements

Step & Shoot Cardiac scans can result in a dose savings of up to 80% compared with a retrospectively gated helical technique (bar graph), while maintaining optimum image quality¹.

Chest / Abdomen / Pelvis (CAP) – Weight Specific Protocols

Patient weight	Relative mAs or CTDI _{vol} dose
Newborn to 10 kgm	0.2-0.4
10 to 30 kgm	0.6
30 to 50 kgm	0.8
50 to 70 kgm	0.9
70 to 90 kgm (ave. adult)	1.0
Above 90 kgm (large adult)	1.4



Routine Brain – Age Specific Protocols

Patient age	Relative mAs or CTDI _{vol} dose
Infant (up to 12 months)	0.4
Child (1 to 6 yrs)	0.7
Teen (7 yrs to 18 yrs) or average adult head	0.9

Figure 10: Special pediatric scan protocols and tube current reduction factors

Without adjusting scan parameters, smaller patients—particularly children—could receive a higher and unnecessary dose due to reduced beam attenuation as discussed above. Special scan protocols have been developed to lower dose for pediatric and infant CT examinations according to age (for head scans) and weight (for body scans), as shown in the figure above. The protocols were developed with custom-made phantoms, such as the 10cm phantom on the right, to prevent the underestimation of absorbed dose for smaller patients¹⁶, as is the case when using FDA-standard 32 (body) and 16cm adult (head) phantoms. The tube current reduction factors shown suggest mAs settings relative to ALARA-optimized adult protocols, and they can be further adapted according to the clinical indication, imaging objective, and physician preferences.

These pediatric protocols are used in combination with dose reducing tools, such as the infant wedge filter (Figure 7) and the Eclipse collimator, to provide multiple advantages and a comprehensive solution for pediatric dose management. (See also Section 5.)

Performance measures

Since dose is proportional to mAs, the reduction factors for pediatric and infant protocols can result in a dose reduction up to 80% relative to adult scan protocols. For newborns, the Image Gently alliance presently recommends mAs reduction factors of 0.43, 0.42, and 0.74 for abdomen, thorax, and head scans, respectively^{6,10}.

4. Brilliance iCT: intuitive dose reporting facilitates optimization of scan protocols

Advances in the Brilliance iCT platform also include intuitive reporting and recording of estimated dose, dose reduction, and dose efficiency. This feedback enables intra- and inter-scan assessments and comparisons of estimated dose levels. It can also be used in conjunction with image quality reviews to optimize scan protocols.

Dose estimates are displayed on the operator's console for all scan protocols prior to and throughout the examination (Figure 11). Volume dose index ($CTDI_{vol}$), dose-length product (DLP), and geometric dose efficiency are automatically updated as the operator plans the scan. Also, a dose report is included as a DICOM secondary capture with the reconstructed data set (Figure 11, right). It includes the percentage dose savings from dose reduction tools, such as Z-axis dose modulation (Z-DOM).

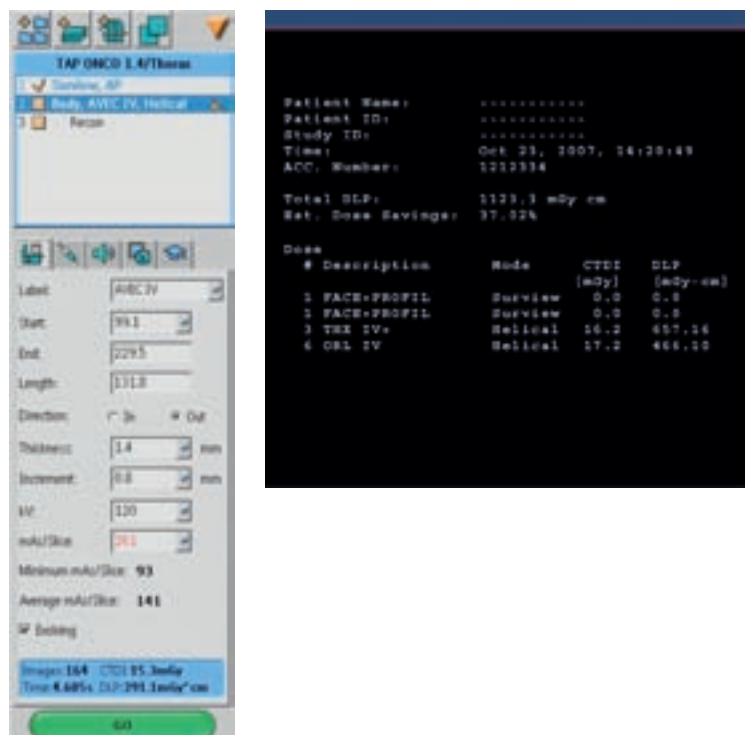


Figure 11: Reporting of dose estimates Predicted $CTDI_{vol}$ and DLP are automatically updated while planning the scan as shown with a helical body protocol (left). A table of dose estimates is recorded with the patient images (right).

5. Clinical results with the Brilliance iCT and DoseWise strategy

In the clinical setting, the Brilliance iCT innovations described above are used simultaneously and the dose savings from each applicable dose reduction technology are automatically combined. This helps manage doses ALARA while considering many patient factors and the clinical imaging objectives for routine and emerging applications throughout the patient care cycle from diagnosis to therapy.

Clinical results from abdominal, chest, and brain examinations show how routine scans can be performed with doses ALARA. Pediatric imaging results show how special dose reduction techniques can be easily applied. Dose reduction strategies for emerging applications that enable imaging earlier in their respective care cycles are represented by Step & Shoot Cardiac and CT colonography. CT brain perfusion results exhibit how cumulative dose may be managed during the acute and subacute phases of treatment, while supporting time-critical treatment decisions. Low dose CT is used in treatment follow-up to assess the healing stage of the care cycle and is shown with radio frequency ablation images. Application-specific advantages for dose and IQ optimization are described, and doses ALARA are summarized in Table 2.

Abdominal examinations

As with all types of CT procedures¹⁸, the annual volume of abdominal CT examinations has steadily increased, and CT is used at least an order of magnitude more frequently than MR¹⁹. This includes a wide range of abdominal indications and pathological conditions such as small and inconspicuous cancerous lesions, infections and inflammatory processes, kidney and bladder stones, vascular abnormalities (CTA), injuries (trauma scanning),

and many others. Single and multiphase scan protocols must provide sufficient contrast detail and minimal scatter and motion artifact with doses ALARA for small as well as large patients. The Brilliance iCT's advances described above such as the NanoPanel^{3D}'s ClearRay anti scatter collimator (ASC) can simplify these challenges with inherent dose efficiency and IQ improvements (Section 2 and Table 1 of the Appendix) for axial, multiplanar, and 3D image review. Applicable dose reduction tools (Section 3) include the Eclipse collimator, automatic current selection (ACS), and Z-DOM which adjusts tube current for patient size. Figure 12 depicts a contrast enhanced abdomen and pelvis scan using 9.1 mSv. (Also see Table 2.)



Figure 12: Coronal view from abdomen and pelvis scan performed with 9.1 mSv including a Z-DOM dose savings of 20%

^f Scan protocols can vary with the preferences of the interpreting radiologist.

^g Effective doses per dose-length product (k) from reference¹⁷.

Table 2: Low dose protocols achieved with the Philips Brilliance iCT^{f, g}

Exam type	Scan mode	kVp	mAs	CTDI _{vol} mGy	DLP mGy*cm	k factor mSv/(mGy*cm)	mSv
Adult abdomen and Pelvis	Helical	120	160	11.4	609.8	0.015	9.1
Adult chest	Helical	140	20	2	84	0.014	1.2
Pediatric head	Helical	120	200	38	494	0.0032	1.6
Step & Shoot Cardiac	Axial	120	200	16.3	204	0.014	2.9
CTC	Helical	90	13-20	~1.5	~52	0.015	0.7-0.9

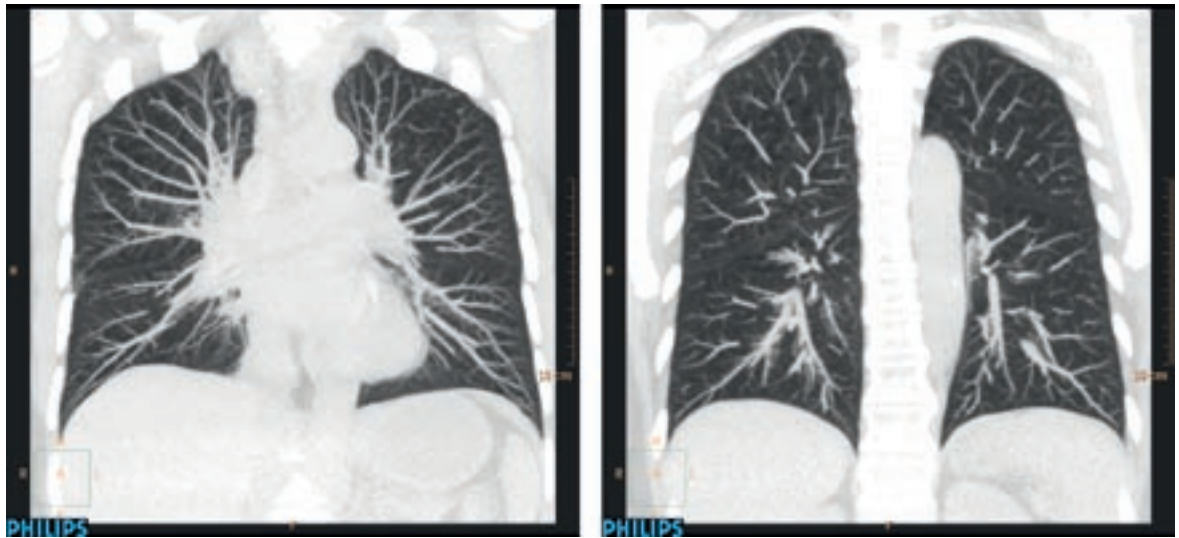


Figure 13: Low-dose Lung nodule scan performed on the Brilliance iCT with 1.2 mSv.

Thoracic examinations

Thoracic CT is one of the most common MDCT examinations and has an important role throughout the lung cancer care cycle—from early detection, to diagnosis, to treatment planning, to assessment of therapy response. A patient at risk for or diagnosed with lung cancer can receive several CT scans in the course of his or her care; therefore, minimizing cumulative radiation dose for thoracic exams must be considered. Since the thorax has inherently low X-ray attenuation and high contrast due to the presence of air in the lungs, Z-axis dose modulation (Z-DOM) can be used to achieve dose reductions up to 50% while maintaining sufficient contrast detail. Low dose scan protocols—approximately 1 mSv—can be achieved for pulmonary lung nodule imaging studies (Figure 13) without compromising image quality.

In addition to lung cancer, another common indication for a CT chest scan is to rule out pulmonary embolism (PE). As a result of its proven benefits and availability²⁰, the use of CT pulmonary angiography (CTPA) is increasing in emergency departments²¹. With this increase, there has been more focus on improved dose management. Also, PE is one of the leading causes of non-obstetric chest pain and discomfort in pregnant women. Therefore, CTPA scans can be indicated for pregnant women, increasing the need to perform exams

with doses ALARA or lower. IQ advances of the Brilliance iCT (section 2 and Table 1) leading to higher spatial resolution and less motion artifact are particularly helpful for CTPA diagnosis. Combining these with integrated DRTs such as Z-DOM can lead to improved 3D evaluation of segmental and subsegmental pulmonary emboli with doses ALARA.

Brain imaging

Brain imaging accounted for 14.5 million CT exams in the United States, or approximately 21% of the annual CT procedures in 2007¹⁸. Optimal image quality is paramount for bone-brain interface and grey-white matter differentiation. At the same time, the volume of brain scans and the varied patient populations that are subject to brain imaging implore the reduction of doses ALARA. Innovations for the Brilliance iCT and its dose reduction tools simplify this optimization. The ClearRay anti-scatter collimator and the IntelliBeam filters can result in better uniformity and low contrast resolution for challenging regions such as the posterior cranial fossa. The Eclipse collimator also reduces over-ranging for helical brain scans. Of all populations subject to brain imaging, children, along with women of childbearing potential, are the most sensitive. As such, brain images illustrating the dose saving benefits of the Brilliance iCT are reviewed in the following section on pediatric imaging.

Pediatric imaging

Dose management for pediatric exams has recently received the most attention among MDCT applications¹⁵. Alliances such as Image Gently^{6,10} exemplify the importance of partnerships and dose training programs in the CT community and these are integral to DoseWise (Figure 1). Reducing X-ray dose without compromising image quality can pose unique challenges for pediatric exams. Surveys have shown that dose management is inconsistent among radiology departments, including the use of adult protocols for pediatric patients at some institutions^{6,10}.

The Philips DoseWise philosophy places special emphasis on pediatric dose management. Custom-designed pediatric phantoms have been developed to better estimate dose and to develop dedicated pediatric low dose protocols (Figure 10)²². The Brilliance iCT's fast volume imaging in the axial or helical mode can

provide a significant image quality improvement such as decreased motion artifact for infants and young children (under 5 to 6 years old) who are restless and may have difficulty holding their breath. Use of a wider detector and true cone-beam reconstruction (COBRA) can reduce the number of rotations needed, thus increasing dose efficiency. Eclipse's over-range reduction is particularly relevant for the short helical lengths typically used with pediatric scans (Figure 8). The Step & Shoot and related techniques can be used on selected pediatric cases to detect cardiac or vascular abnormalities, or for follow-up after surgery, with doses as low as 0.5 mSv. Integrated dose reduction technologies, such as the IntelliBeam filter (Figure 6) and the infant wedge (Figure 7), can be used to optimize both dose and image quality. Figure 14 shows a routine pediatric brain scan acquired with a tube current reduction factor resulting in an effective dose of 1.6 mSv (Table 2).

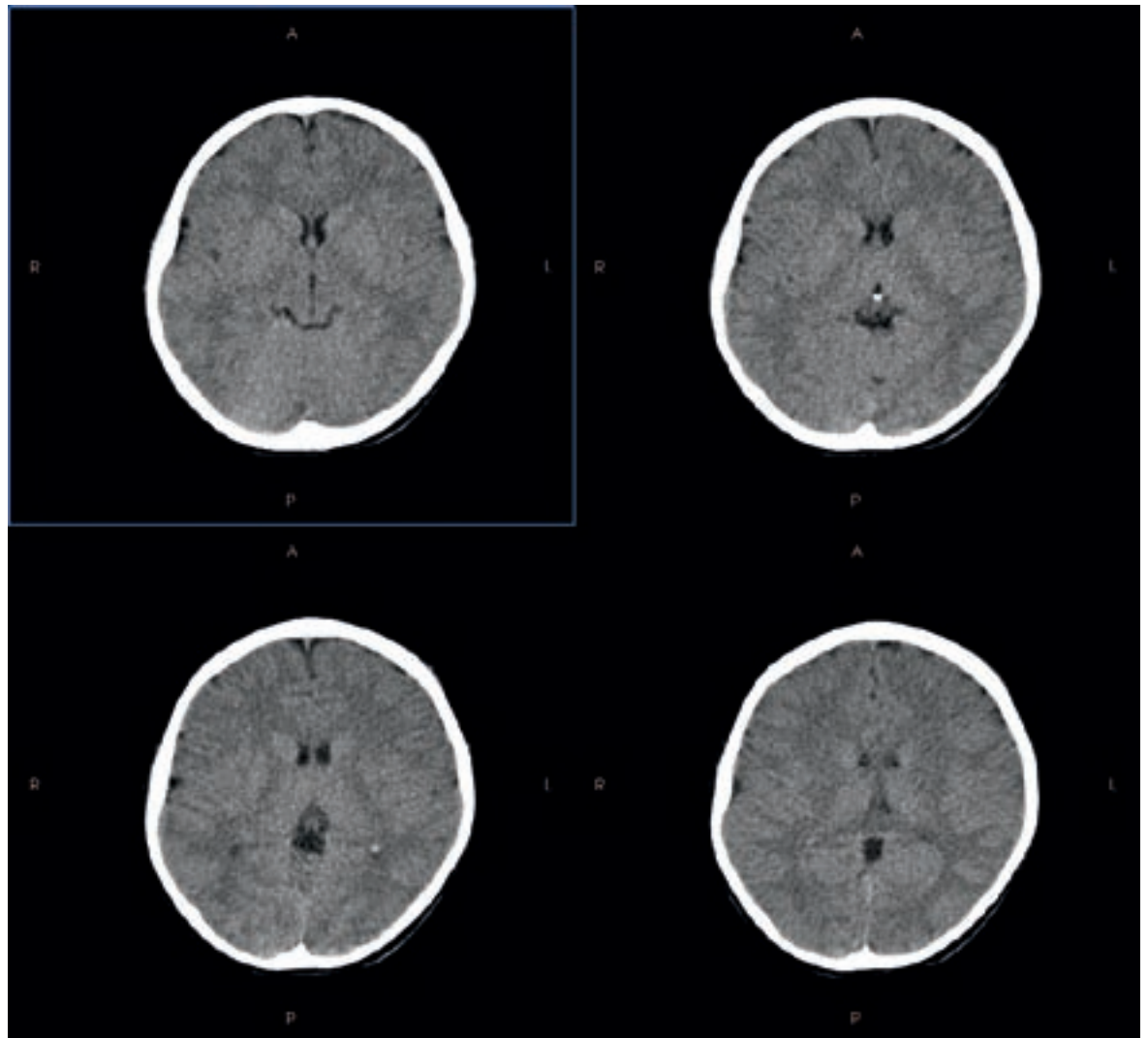


Figure 14: Pediatric brain images scanned with special techniques resulting in an estimated effective dose of 1.6 mSv.

Step & Shoot Cardiac imaging

Imaging of the beating heart has been atop the list of emerging MDCT applications. Coronary CT angiography (CCTA) (Figure 15) can provide a quick, non-invasive test for indications such as suspected coronary artery disease (CAD), evaluating bypass grafts, coronary stents and surgical follow-up, and electrophysiology treatment planning and follow-up. Imaging of the fast-moving, small-caliber coronary arteries with sufficient contrast detail can, however, pose challenges for MDCT. For many years, there has been a need for new, advanced scan protocols that reduce dosage in CCTA without sacrificing image quality and diagnostic value, and it has been observed that there is a significant variance in CCTA dose among sites and scanners⁵.

The high performance volume imaging of the Brilliance iCT—with its improved speed, power, and coverage (Section 2)—can help meet the challenges of high quality, cardiac imaging for wider patient populations, while significantly reducing dose with techniques such as Step & Shoot Cardiac. This prospectively-gated axial technique makes use of the Brilliance

iCT's 8cm NanoPanel^{3D} detector and true cone-beam reconstruction (COBRA) to enable coverage of the cardiac anatomy in one step. In addition, the full set of integrated dose reduction technologies (Section 3), such as the cardiac wedge and the IntelliBeam filter, are also automatically employed for all cardiac exams.

The Step & Shoot Cardiac technique also utilizes an exclusive real-time arrhythmia handling mechanism. When arrhythmias are detected, the scan is stopped to prevent unnecessary dosage, and the anatomic region is then scanned after the ECG signal stabilizes.

Intelligent advances in Essence technology and integrated dose reduction tools enable CCTA doses as low as 1-2 mSv for the average adult and 0.5 mSv for children and thin adults. This represents a dose reduction of up to 80% compared with retrospectively-gated methods, while maintaining the same image quality¹. This not only meets the aforementioned need for high-quality cardiac imaging at a lower dose, but paves the way for cardiac imaging in a wider patient population, as well as imaging earlier in the cardiac care cycle.

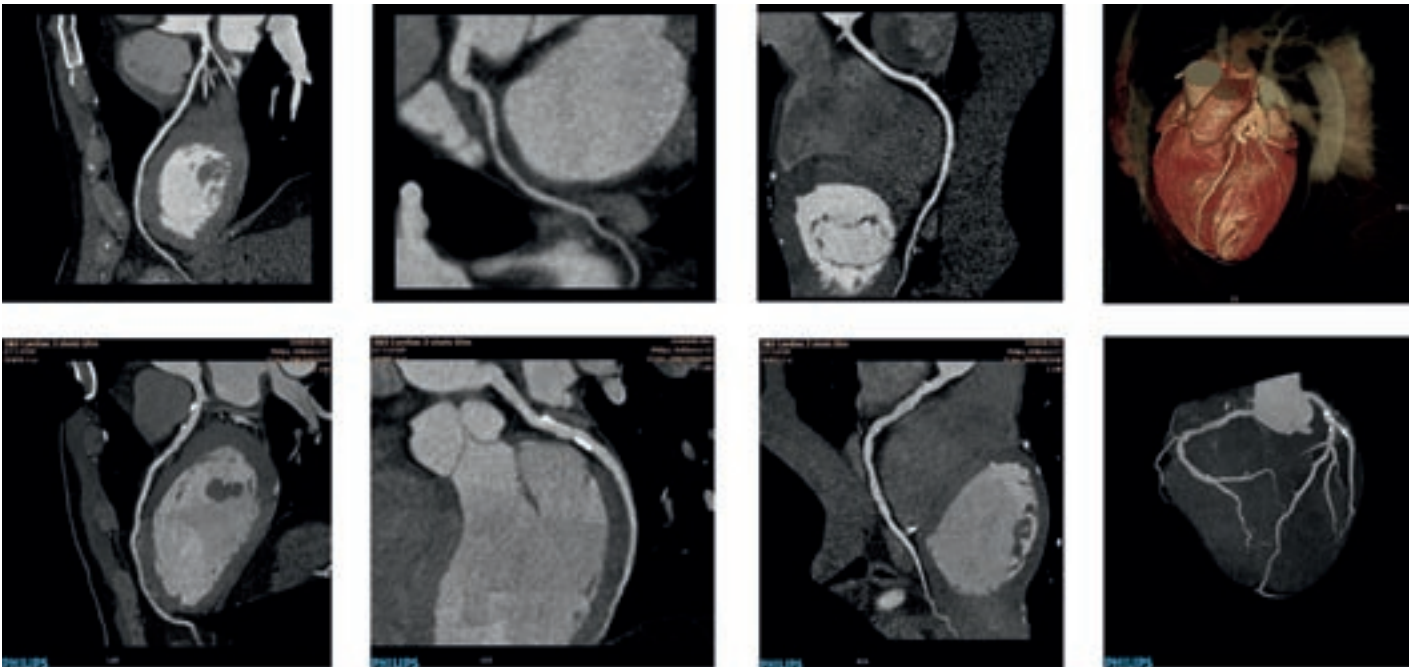


Figure 15: Cases demonstrating Prospectively gated Step & Shoot coronary CT angiograms with doses as low as 1-2 mSv

CT colonography (CTC)

CT colonography represents an emerging abdominal application at the earliest stage of the colorectal cancer care cycle. Colorectal cancer (CRC) is the second leading cause of cancer deaths in United States. CRC can develop slowly from precancerous polyps, and it can often be prevented if detected early. This indicates the importance of early detection of colorectal cancer; however, patient compliance with screening recommendations remains extremely low due to the limitations and unpleasantness of current non-CT based techniques^h. CT colonography (CTC) (Figure 16) was recently endorsed in a joint guideline published by several societies and agenciesⁱ as a means to detect adenomas and CRC. This guideline included a recommendation for CTC at five year intervals, starting at the age of 50 (45 years for African Americans). It was recognized that some patients may require a more frequent follow-up based on the clinical outcome.

Since CTC is primarily intended for scanning asymptomatic individuals and since both a supine and prone scan is presently used with each procedure, it is important that the radiation exposure remains ALARA while maintaining sufficient axial image quality for extra-colonic review. The ACRIN 6664 trial was performed with a low dose CT technique that had an average dosage of 4-5 mSv per exam. Although the risk from CTC dose is considered to be low, the Brilliance iCT platform can further decrease doses for this emerging application as with routine abdominal imaging. These advances, along with continued CTC trials, are expected to facilitate a rapid adoption of this new application.

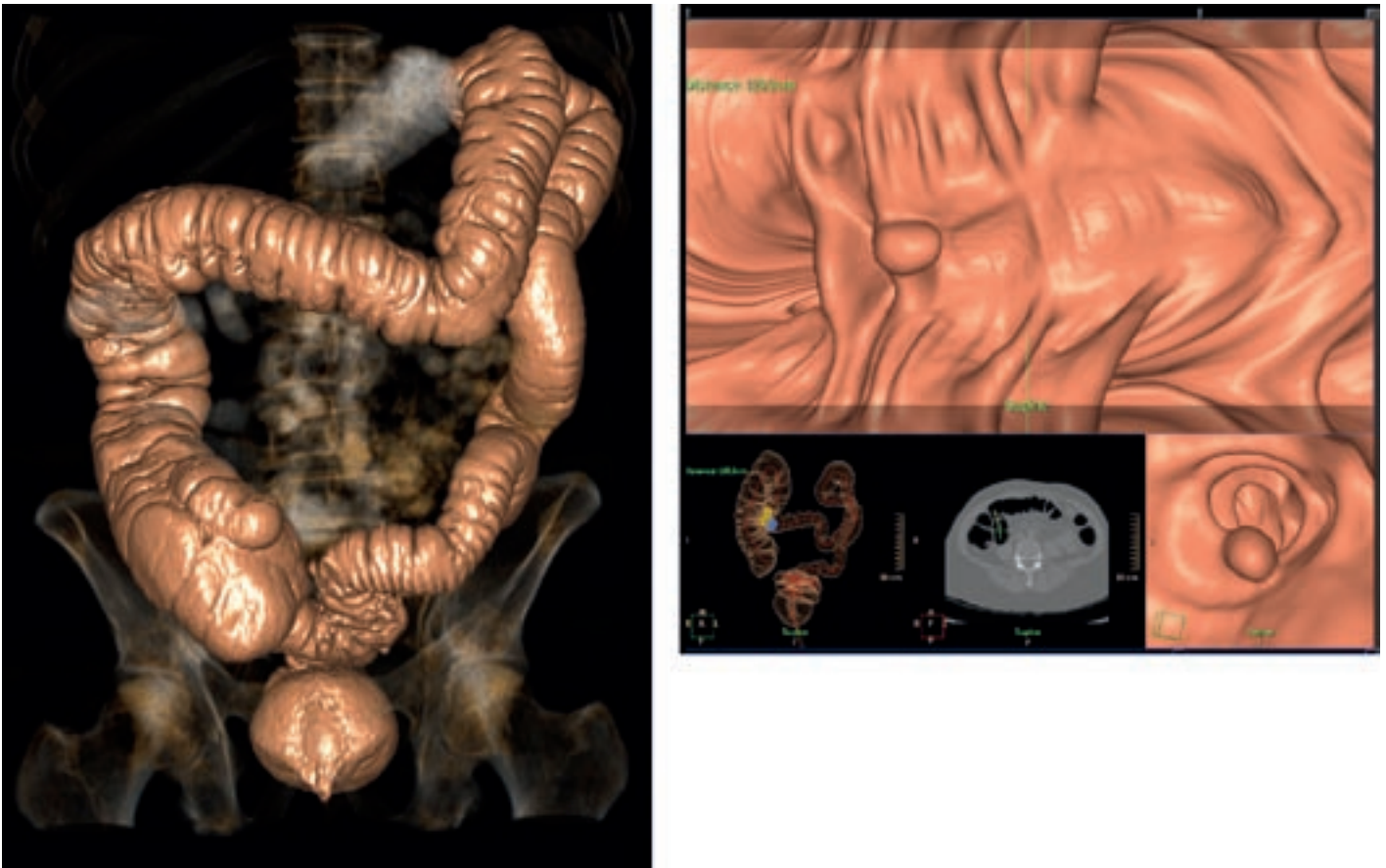


Figure 16: CT colonography exams can achieve dose levels as low as 0.7 mSv² for combined supine and prone scans.

^h Examples include optical colonoscopy, flexible sigmoidoscopy, fecal occult blood test.

ⁱ This includes the American Cancer Society, the U.S. Multi-Society Task Force on CRC, and the American College of Radiology.

Brain perfusion

The American Heart Association (AHA) recommends imaging, including routine noncontrast head CT, for the initial evaluation of patients presenting with stroke-like symptoms to rule out stroke-mimicking conditions, to identify other conditions requiring immediate attention, or to assess whether a stroke is of ischemic or hemorrhagic nature. These guidelines also recommend imaging prior to any intervention or therapy for stroke²³. An extended protocol that includes a noncontrast head CT, CT perfusion, and CT angiography in the assessment of ischemic stroke has the potential to effectively triage patients and to reduce the length of hospital stay²⁴. This same protocol may also provide additional treatment options for stroke by extending the critical time windows for the administration of thrombolytic therapies such as recombinant tissue plasminogen activator (tPA). The Brilliance iCT brain and stroke imaging solutions enable these clinical and economic benefits and facilitate timely treatment decisions, while also facilitating the effective management of cumulative radiation dose.

Perfusion studies require dynamic, wide coverage imaging in the axial mode to measure the flow of blood, as shown with contrast uptake, to a tissue of interest; nevertheless, the radiation dose from a CT brain perfusion study performed using a lower dose technique protocol (80 kV, 100-150 mAs; approximately 1.6-2.0 mSv) is less than the radiation dose from a conventional cerebral CT exam (approximately 2.5 mSv)²⁵. This perfusion protocol, which is the default for the Brilliance iCT, has been shown to generate images with diagnostic quality similar to those with 2.8 times higher dose, thus allowing rapid and safe imaging of the entire neurovascular axis²⁶ and a 95% accuracy in the delineation of supratentorial ischemia²⁷. In addition, it can be adjusted with age-specific reduction factors (Figure 10)^{28, 29}. Philips has also developed advanced image filtering technology to reduce the effects of image noise while preserving image features, as well as facilitating accurate and reproducible brain perfusion parameters^{30, 31}. These filters are implemented for this application on the Extended Brilliance Workspace and the Brilliance Everywhere Portal.

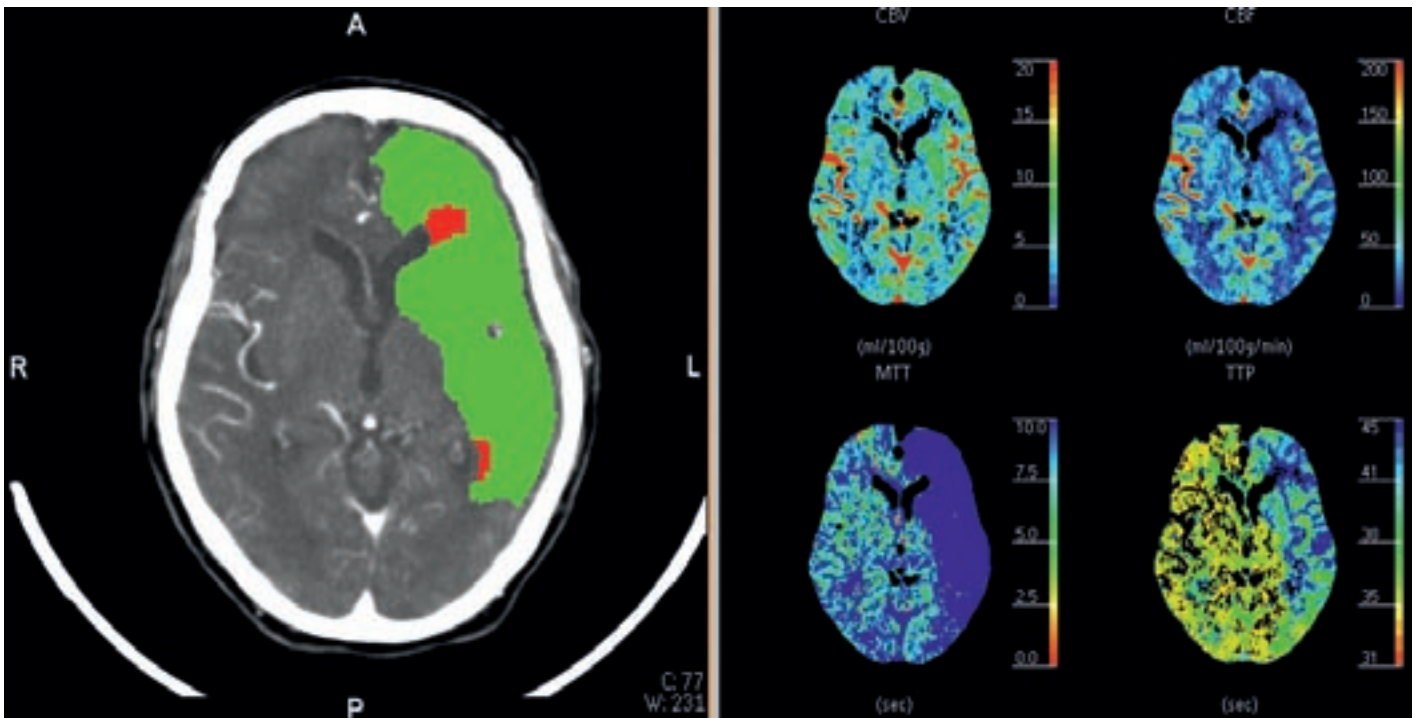


Figure 17: CT brain perfusion application showing brain perfusion parameter maps (right four images) and summary map overlays (left) demonstrating areas of ischemic penumbra (green) and infarct (red). The images were acquired using a lower dose protocol on a Philips Brilliance CT scanner.

Treatment monitoring and follow-up scans

MDCT can be of considerable value during follow-up evaluations and for tracking response to treatment. Examples from oncology include response evaluation criteria in solid tumors (RECIST) studies, mapping contrast enhancement throughout a chronic hepatocellular carcinoma, imaging following radiofrequency ablation (Figure 18), and detection of tumor recurrence or metastasis following surgery or radiation therapy.

The advances in the Brilliance iCT platform discussed above can make it easier to manage and monitor cumulative dose ALARA when multiple follow-up CT scans are indicated. Figure 18 shows an example from the growing field of interventional oncology involving post-ablation monitoring for residual tumor. Cumulative doses can be easily tracked in the dose reports provided with the DICOM images. The treatment follow-up applications demonstrate how the Brilliance iCT and DoseWise strategy can bridge the gap between diagnosis and therapy while managing cumulative dose.

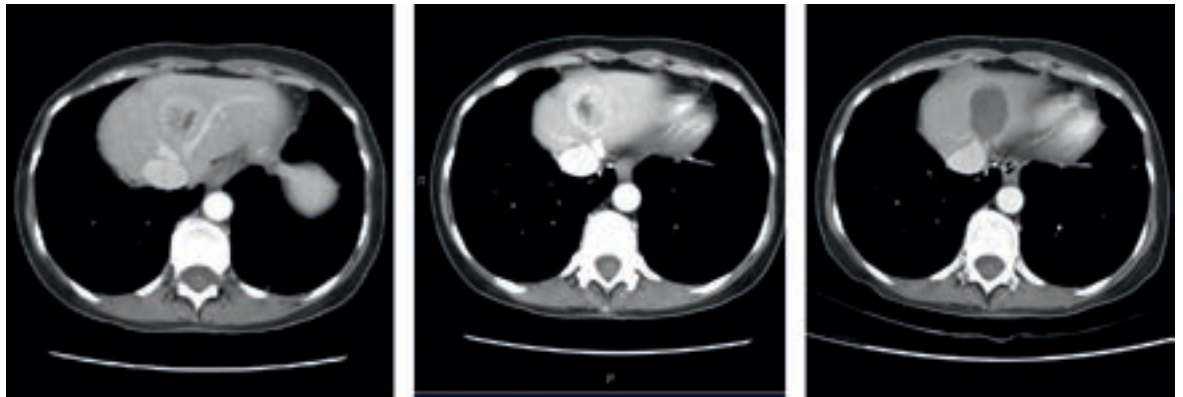


Figure 18: Low dose CT imaging with optimized image quality can be used in the pre-, intra- and post-procedures stages of percutaneous radiofrequency ablation (left, middle, and right, respectively).

6. Summary

The advances of the Brilliance iCT platform, developed with DoseWise strategies, far exceed the performance trends of MDCT. They were designed to not only meet regulatory dose guidelines, but to increase dose efficiency and optimize image quality thereby helping to achieve doses ALARA for ever-widening patient populations. This was achieved by scaling up Essence technology and integrating dose reduction technologies in each stage of the imaging chain. These advances simplify the delivery of the right quantity and quality of radiation where and when needed for routine as well as challenging examinations.

The DoseWise philosophy also includes ongoing investments in innovative research and development and clinical collaboration. These investments have led to the emergence and adoption of new low dose applications. Further dose reductions will be achieved with advanced image reconstruction and analysis methods that decrease image noise while preserving or enhancing diagnostic and therapeutic information. Beams will be dynamically shaped, filtered, modulated, and localized according to the reason for scanning and the tissue to be scanned. Dose estimates will be reported and recorded more accurately, taking into account patient size, shape, and tissue sensitivity. An array of new low dose CT applications will emerge such as those low enough to replace the radiograph. New partnerships and alliances will be forged to update ALARA practice standards, including education and reporting, and to provide a forum for sharing low dose scan protocols and techniques.

Together in clinical partnership, the Brilliance iCT platform and the DoseWise strategies embolden a vision of a new era of expanding MDCT use, fueled by increasing clinical benefits and decreasing doses. This vision shows the way to routinely detect disease before the onset of symptoms and provide timely information to improve treatment decisions, leading to better patient care.

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Appendix

			iMRC Tube	NanoPanel ^{3D}	RapidView Reconstruction	Additional components
						
	Fast volume imaging		Increases output capacity—up to 120 kW—when needed for applications such as Step and Shoot Cardiac.	Wider detector coverage (8cm) per rotation. Faster 128 channel read-out.	Fast reconstruction with Intel Multi-Core processors. 3D back projection board.	AirGlide gantry that enables the fastest tube rotation in the industry (0.27 sec per rotation).
	IQ enhancements	improved temporal resolution decreases gross motion artifacts.	Smart focal spot (stability and multiaxis deflections) increases spatial resolution.	Minimum slice thickness 0.625, 256 slices per rotation. Spherically shaped for true cone beam geometric focus. TACH 2 chip: decreases (low frequency) electronic noise by 7% for imaging with low photon counts.	True cone-beam reconstruction (COBRA). Adaptive filtering enhances image quality and mitigates artifacts.	ClearRay 2D Antiscanner Collimator (Figures 3, 4) lowers the scatter-to-primary — improves contrast detail for low dose imaging.
Dose management	Inherent IQ enables opportunities for lower dose scan protocols.	Decreases in motion artifact can enable use of less dose.	Provides sufficient flux for selective filtration.	Increases Z-axis dose efficiency with 8cm detector. GOS detectors with higher absorption efficiency (98% in center).	Maximizes cone-beam geometry to prevent unused radiation exposure.	Build in patient-adaptive and protocol-drive DRTs(Section 3). Optimized source to isocenter distance. Eclipse Collimator: reduction of helical over-ranging (Figure 8).

Table 1: Essence technology is foundational to the Philips Brilliance iCT and 64-slice configurations. Further advances have been introduced for the Brilliance iCT that provide fast volume imaging and simplify dose management with optimized image quality. These advances work in concert with a wide range of automatic dose reducing tools.

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