iPatient

Patient-centered CT imaging: New methods for patient-specific optimization[1] of image quality and radiation dose

iPatient is an advanced platform that delivers focused innovations to facilitate patient-centered imaging, now and in the future. Based on the award-winning EBW, iPatient puts you in control of innovative solutions that drive confidence and consistency through personalized patient-centric workflow. It helps you deliver more from your investment by allowing you the ability to do complex and advanced procedures, and helps to prepare for future CT technologies that will help improve the care you deliver to your patients.

The patient-centered approach to imaging is an increasing focus in Radiology departments. For patients undergoing CT, this includes a personalized examination, one that provides diagnostic image quality while managing radiation dose (As Low As Reasonably Achievable, or ALARA). The Philips iPatient approach to patient-centered imaging includes new, patient-specific methods to facilitate optimal management of both image quality and radiation dose.

These methods were designed to simplify the adaptation of scan protocols and advanced techniques – such as dose modulation and iterative reconstruction techniques – to the individual patient and diagnostic task. They are used in combination for a synergistic effect that is amplified by dose-efficient imaging components of the iCT and Ingenuity CT platforms.

In the iPatient approach, considerations for optimizing[1] CT image quality and dose include clinical indication, body habitus (from infants to morbidly obese adults), scan region, age, and physiological and anatomical factors (Figure 1). Patient-specific imaging factors and solutions are reviewed for obese, pediatric, and cancer patients as well as trauma, chest, and cardiac examinations.

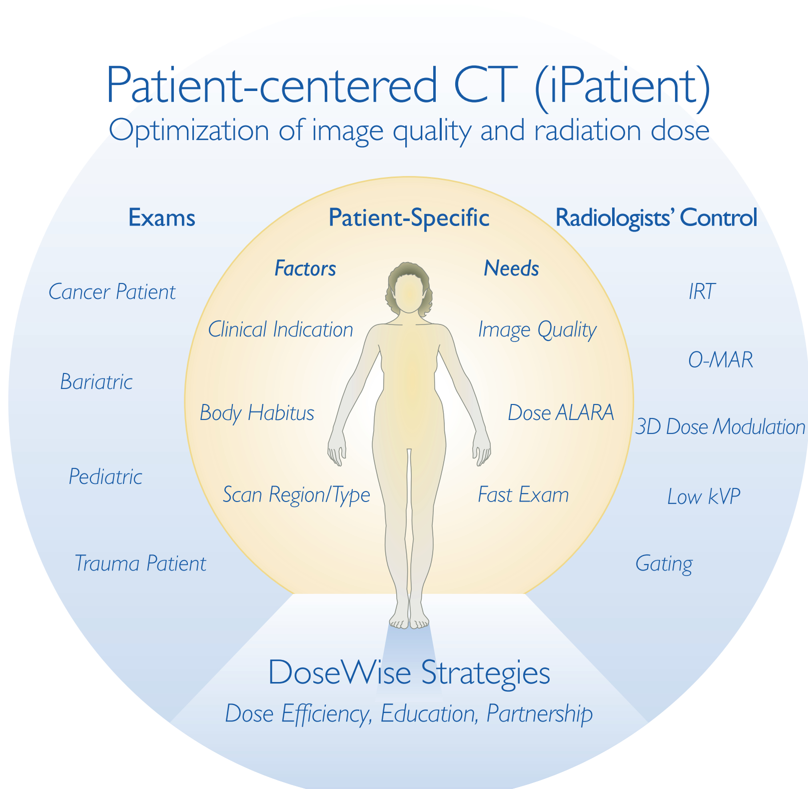

Figure 1

[1] "Optimization" refers to the use of strategies and techniques that facilitate the management and control of both image quality and dose.

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Obese patients and DoseRight index and 3D

Globally, it is estimated that more than 1 billion adults are overweight and at least 300 million are obese.[1] In some CT departments, scan protocol settings used for obese patients balance a trade-off between:

- Increased radiation exposure that can be required due to relatively higher body attenuation[2]
- The quantum image noise that can result from insufficient dose.

To help manage this, the iPatient approach includes new settings and methods for dose modulation and iterative reconstruction techniques that are not only designed to be intuitive but also complementary. These include:

- The image quality reference setting ("DoseRight Index," DRI)
- An iterative reconstruction technique (IRT) setting
- The scan protocol reference size, D_{ref} (Table 1).

These are conveniently displayed with other patient-specific parameters prior to data acquisition.

For dose (tube current) modulation, the patient's CT radiograph (Surview) is used to create an average and z-axis profile attenuation (represented in terms of water equivalent diameter, D_w). The **water equivalent diameter** represents the size of a circular water phantom that would provide the cross-sectional attenuation characteristic of the patient.

The DoseRight CS algorithm suggests adjustments to average tube current and image noise based on

- The DRI
- The difference between the average diameter, D_w, in the scan region (assessed from the Surview) and the reference diameter, D_{ref} .

The z-axis D_w profile can be highly variable and individualized. For example, the chest region can have a much lower average attenuation than the abdominal region due to air in the lungs. DoseRight Z-modulation adjusts the tube current profile along the z-axis to maintain approximate constant noise and displays the profile in correlation with the Surview.

Patient-specific parameters and settings	
Image quality	• DoseRight index (DRI) setting • Iterative reconstruction technique (IRT) setting • Estimated image noise
Patient size	• Water equivalent diameter (D_w) relative to the reference diameter selection (D_{ref})
DoseRight CS	• mAs or avg. mAs with Z- or 3D modulation

Table 1

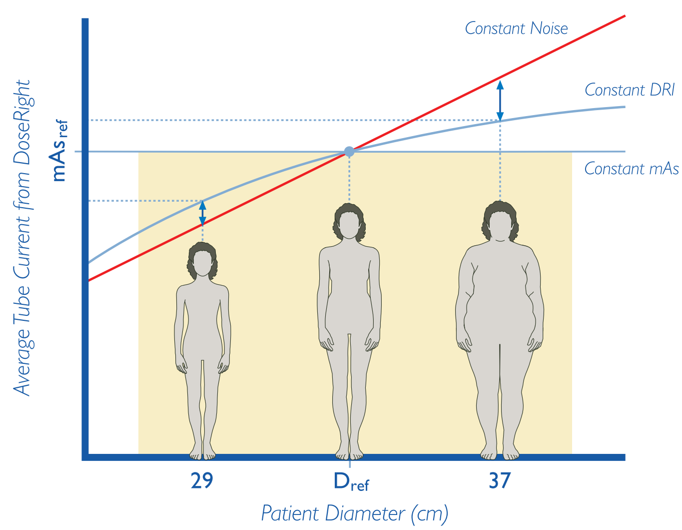

Figure 2 DoseRight CS suggests appropriate tube current settings (vertical axis) over a wide range of patient sizes (horizontal). The DRI, IRT and other settings in Table 1 are easily combined to optimize according to patient factors and needs.

[2] For obese patients, absorbed dose tends to be overestimated by the 32 cm CTDI body phantom.[4,5]

The DoseRight Index (DRI) – used to specify the image quality required for the diagnostic task at hand – and the DoseRight Current Selection (CS) algorithm were developed in extensive clinical collaboration. For an obese patient, when the patient's diameter (D_w) is greater than the reference diameter (D_{ref}), e.g., D_w = 37 cm and D_{ref} = 33 cm, DoseRight CS suggests an increase in the average tube current[3] (green curve in Figure 2)[4] relative to the reference diameter and according to the specified DRI. The suggested increase does not occur at the exponential rate that would be required to maintain constant noise level (red line) with increasing patient size (D_w). For this, the tube current would need to double about every 4 cm increase of D_w (double arrow). Sagittal CT images of an obese patient with D_w = 42 cm are shown in Figure 3. To plan the same level of quantum image noise as a patient with reference diameter of 30 cm, the tube current would need to increase by a factor of 8 (((2)x2)x2 = 8) – to 784 mAs. Instead, a controlled increase in suggested noise levels for larger patients (and a decrease in noise for smaller adults when $D_w < D_{ref}$) was found to be most appropriate for managing dose and image quality. To further optimize image quality and manage dose, the iPatient approach provides additional options (Table 1):

- The iterative reconstruction technique, iDose^4, has seven noise reduction settings and preserves the natural image appearance.[5]
- Philips engineers designed the DRI to simplify adjustments: decreasing (increasing) it by -1 (+1) will decrease (increase) the average tube current by 12 % and increase (decrease) the image noise by 6%[6] (further discussed below), with other parameters unchanged.
- Additional size-specific scan protocols can be used if these are preferred. For example, separate protocols can easily be created with reference diameters for obese (37 cm), average (33 cm), and slim adults (29 cm) (as shown in Figure 2) – each with a DRI and iDose^4 setting. Size-specific scan protocols are particularly helpful with CT pediatric imaging (next section).

"Tools such as iterative reconstruction techniques are changing perspectives on the management of CT image quality and dose."

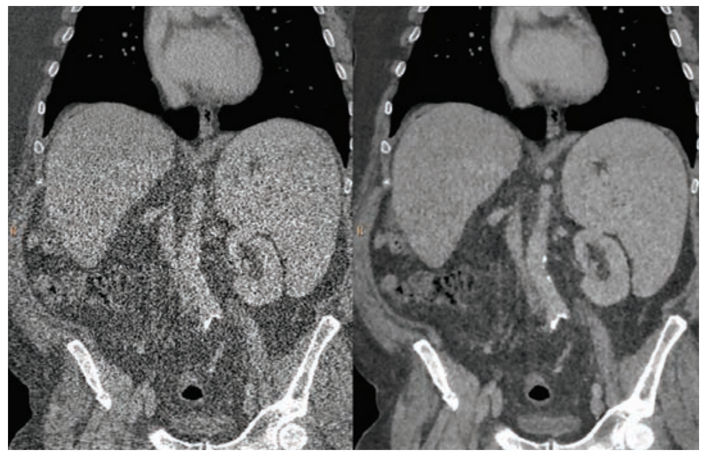

Figure 3 Sagittal reformatted images of an obese patient (D_w = 42) acquired with DoseRight settings of DRI 7 (98 mAs), 120 kVp, and $CTDI_{vol32}$ = 6.1 mGy. Standard reconstruction was used without iDose^4 (left) and with iDose^4 level 2 (right).

Pediatric patients and reference size selections

The need for highly patient-specific pediatric CT examinations has resulted in the Image Gently campaign.[5] Consistent use of the ALARA principle is paramount in this population due to relatively higher radiosensitivity and higher dose absorption of the relatively smaller body volume.[7] Accordingly, pediatric scan protocols need to be appropriately adjusted for patient size – which can vary from infants to adults-sized adolescence.[7] Planning the set of scan protocols is usually based on weight intervals (e.g., 0-10 kg, 10-20 kg, etc.), scan region, and the diagnostic task.

[3] Tube current includes reference to tube current time product (mAs) in this paper.
[4] Tube current suggested by DoseRight CS is used as an average mAs when Z- or 3D modulation is selected and is used as a fixed (constant) mAs otherwise.
[5] iDose^4 can provide up to 57% improvement in spatial resolution for the Ingenuity CT and up to 50% improvement in spatial resolution for the iCT, for a given dose.
[6] As predicted by the Inverse Square Law.
[7] Lower noise levels may be preferred due to less fat planes, smaller structures, and a need for higher diagnostic confidence.

In the iPatient approach, size-specific scan protocols (i.e., Exam Cards) can be easily generated (as mentioned above). Exam Cards can be based on one of eight (1 infant, 7 pediatric) midpoint reference diameters, D_{ref} that are directly related to weight based intervals (as shown in Figure 4). The DoseRight CS algorithm can then adjust the average tube current and image noise relative to a more protocol-specific D_{ref} (Figure 4) and DRI setting. Conversely, using a 6-year-old as reference size for a 10-20 kg weight-based protocol, for example, could be counterintuitive, despite an understanding that the dose modulation algorithm would significantly decrease the tube current according to the size of the individual in the 10-20 kg interval.

Basing scan protocols on the appropriate size or weight groups can improve confidence when comparing patient-specific parameters (such as the patient diameter, suggested tube current, and others in Table 1) with reference parameters. The radiologist can then focus on image quality settings (DRI) to meet the diagnostic objective.

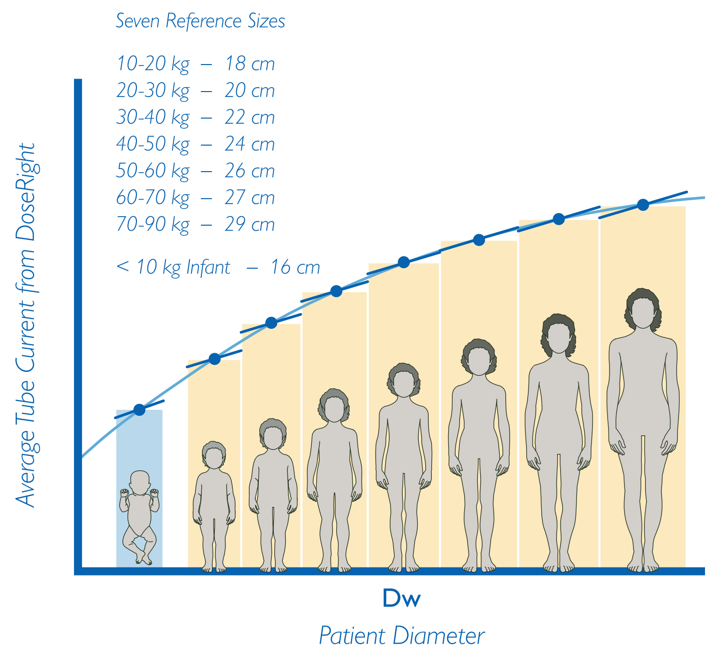

Figure 4 Size-specific selections (horizontal axis) for pediatric and infant protocols allow patient-specific and intuitive control of the DoseRight Index and the average tube current (vertical axis), as needed in this population.

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. Average adults tend to have oval abdominal cross-section. Tube current is angularly modulated during helical scans according to the patients cross-sectional shape (eccentricity). Prior to the helical exam, the A-P Surview is processed at each z-location to determine angular adjustments in the tube current profile. The mAs is increased and decreased for the maximum and minimum cross-sectional diameter respectively.

DoseRight 3D modulation combines angular modulation with z-axis tube current modulation (ZDOM). The 3-D modulation can be implemented based on the acquisition of one Surview, the DRI setting, and the reference diameter.

Oncology imaging: organ-based dose modulation and iterative reconstruction techniques

CT is the examination of choice for detecting or evaluating liver lesions. This diagnostic task can pose challenges due to low contrast of the lesions.[2] Another feature of the iPatient approach to help optimize image quality and manage radiation exposure are organ-based adjustments with the DRI during dose modulation. This new method for the liver (and also the brain), goes beyond use of body eccentricity and attenuation characteristics. A new algorithm is used to detect the liver in the Surview and assist with the placement of organ delineation lines. The Z-axis tube current profile is then adjusted with a protocol-specific DRI setting. Figure 5 illustrates changes in beam intensity as the tube rotates from lateral to A-P (Angular Modulation) and to the liver region. This advanced technique enables an increase in image quality where needed without increasing radiation exposure to other regions or organs.

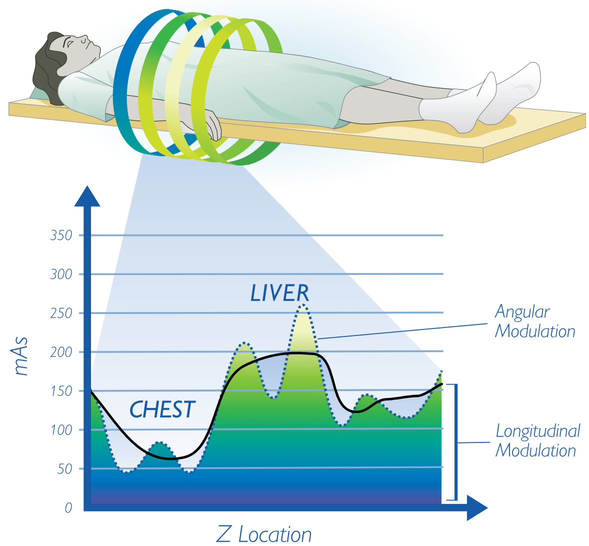

Figure 5 3D dose modulation adjusts angular and longitudinal exposure according to body habitus and the DRI. The DRI can be adjusted for the liver region in conjunction with settings for Iterative Model Reconstruction (Table 1).

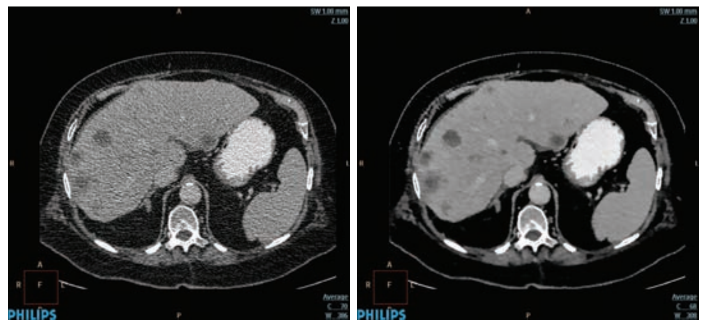

Figure 6 Abdominal CT images acquired with 3D modulation and an increased DRI for the liver. These techniques were used in conjunction with Iterative Model Reconstruction (IMR) (right) shown in comparison with standard reconstruction (left).

The strategy of increasing exposure to facilitate diagnostic confidence for liver lesions is consistent with the ALARA principle. To further optimize image quality and manage dose for this challenging task and many others, Philips provides an advanced method – Iterative Model Reconstruction (IMR) – for exceptional image quality improvements. IMR provides virtually noise-free* images with significant improvements in low contrast imaging (Figure 6). Consistent with the iPatient strategy, IMR can be adapted for the diagnostic task at hand: it has settings to emphasize low or high contrast resolution or both.

Managing low dose (ALARA) scan protocols with the DRI

A number of high contrast studies, for example, CT colonoscopy, calcium scoring, and some chest examinations, can occur earlier in the care cycle and have potential for low dose. This must be achieved without risking a non-diagnostic exam. A common practice is to gradually reduce the volume CTDI, review the results in terms of image quality and dose, and then consider the potential need for further optimization (Figure 7).

CT image quality and radiation dose management cycle

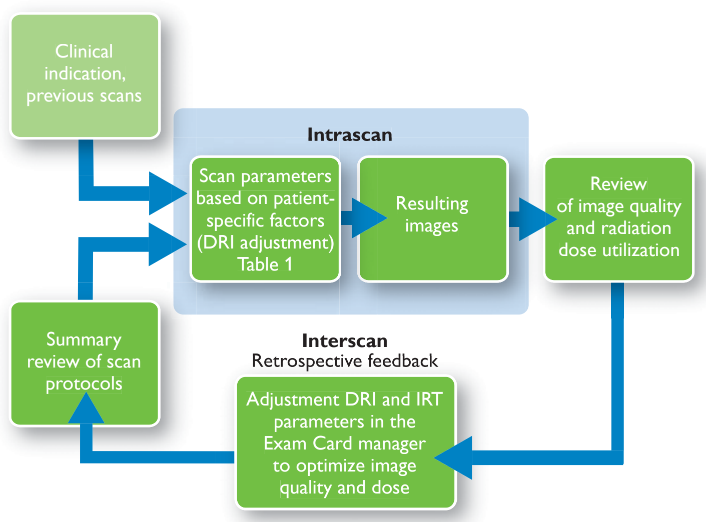

Figure 7 Flow chart exemplifying CT image quality and dose management based on the ALARA principle. Reviews and adjustments of scan protocols are facilitated by the iPatient approach.

*In clinical practice, IRT may reduce image noise depending on the clinical task, patient size, anatomical location, and clinical practice. A consultation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular task. As with any imaging reconstruction, the quality of the resulting IRT images is dependent on the scanning parameters required for your particular patient, clinical indication, and clinical practice.

As mentioned earlier, Philips engineers designed the DRI so that a step of one will change the volume CTDI by 12% and noise by 6% if other settings are unchanged.[8] This structured way to adjust and review CTDI and estimated noise levels can be easily combined with iterative reconstruction technique settings to further optimize image quality. After the appropriate number of cycles and consideration of the results, adjustments to the DRI and iterative reconstruction technique settings can then be incorporated into the Exam Card to manage individual patient examinations.

Additional patient-specific approaches with iPatient

CTA exams: DRI and tube potential

For examinations with iodinated contrast media, a decrease in tube potential[9] leads to an increase in iodine attenuation and signal. The decrease in tube potential (with tube current held constant) decreases $CTDI_{vol}$ and, therefore, increases noise in a highly non-linear fashion. iPatient provides a more intuitive approach: if the planned tube potential (kVp) is modified for a particular DRI setting, the average tube current (mAs) suggested by DoseRight CS automatically updates to maintain the same $CTDI_{vol}$. Then, the DRI can be used for more intuitive steps of 6% and 12 % in planned image noise and dose, respectively.

A 16 cm cylindrical phantom with five iodine samples (four peripheral, one central) was used to demonstrate this innovative approach (Figure 8). iCT data was acquired using DRI 28, 120 kVp, and 83 mAs ($CTDI_{vol32}$ = 10.3 mGy) and standard reconstruction (left). The tube potential was decreased to 100 kVp and the tube current automatically adjusted to 250 mAs to maintain the CTDI. The DRI was then incrementally decreased from 28 to 18 (88 mAs and $CTDI_{vol32}$ = 3.5 mGy) and iDose[4] was used with a setting of 6. This resulted in a CNR increase of 45% and increased conspicuity of the center iodine sample (blue arrow).

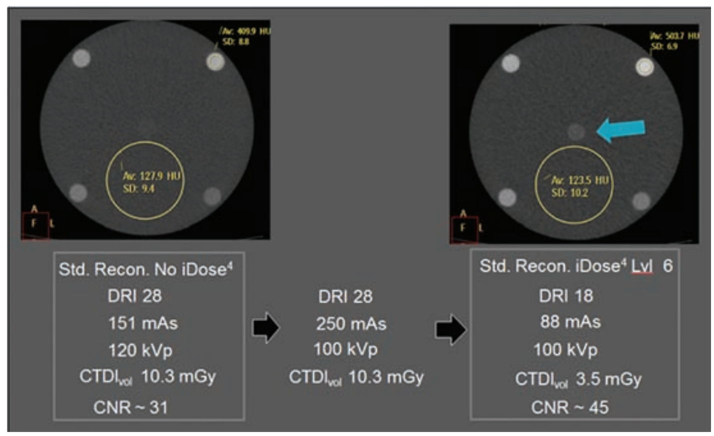

Figure 8 A 16 cm phantom with five iodine samples was used to show how the DRI can simplify adjustments in the tube potential, mAs, and iDose[4]. These adjustments lead to an increase in the CNR at low dose.

Radiation dose metrics are also changing from "one-size-fits all" approaches to more individualized metrics. The size-specific dose estimate,[6] for instance, provides a correction for CTDI based on a measure of effective diameter. This is a step toward patient-specific dose estimates such as organ dose estimation.

Cardiac examinations and DoseRight CS

Low doses have been achieved while maintaining image quality with the use of prospective Step & Shoot and ECG triggered dose modulation for retrospective gated helical scans.[8][9] The iPatient enhancements are fully integrated with these high temporal resolution scan modes of the iCT and Ingenuity CT. As with non-gated scanning modes, DoseRight CS can be used to suggest the average tube current according to patient size and the DRI setting. This applies to Calcium scoring, prospectively-gated Step & Shoot examinations, and retrospective-gated cardiac exams.

[8] Decreasing DRI by 3 from 15 to 12, for example, would decrease the average mAs by a factor of $(1.0 - 0.12)^3 = (0.88)^3 = 0.68$ or (1-0.68)*100% = 32% and would increase noise by a factor of $(1.06)^3 = (1.06)^3 = 1.19$ or 19%.
[9] Many patient-specific factors are considered when adjusting tube potential.

A low-dose feature for trauma examinations

CT is clinically indicated for head trauma and acute abdominal conditions. The speed and diagnostic quality of the MDCT can provide immediate benefit. Brain and cervical spine imaging can be planned in a single acquisition. This is accomplished by semi-automatically detecting the base of the neck in the Surview. The technologist can then adjust the border between the base of the brain and C1 cervical spine if necessary. The scan parameters are set for each region as with those traditionally planned in the dual acquisition mode but without the overlap that would increase the total DLP of the examination.[4]

Imaging orthopedic implants with O-MAR

Metal implants can make diagnosis challenging due to beam hardening artifacts and other effects on image quality. To address this, the set of enhancements provided by the iPatient approach includes Metal Artifact Reduction for Orthopedic Implants (O-MAR) to help improve image quality. O-MAR is capable of reducing the effect of large metal artifacts from orthopedic implants such as hip prosthesis.[3] This can enhance the diagnostic quality of the images.

Summary

Patient-specific CT imaging and personalization of scan protocols will be a key aspect of patient-centered care in Radiology departments. Dose management is also becoming more patient-specific relative to use of the CT Dose Index.[6] iPatient follows the longstanding DoseWise philosophy to provide enhancements that are used in combination for a synergistic effect that is amplified by highly dose-efficient imaging components of the iCT and Ingenuity CT platforms. iPatient includes patient-specific methods to simplify – and easily control when needed – the improved management of image quality and radiation dose. Innovations provided by iPatient will transform patient care by keeping the interest of the patient in the forefront of advanced diagnostic CT imaging.

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