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White Paper

RT Planning with Dual Energy CT

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Dual Energy CT for Metal Artifact Reduction in Radiation Therapy Planning with the SOMATOM Definition AS 20

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Computed tomography (CT) acts as the basis of modern radiation treatment planning. The goal of RT planning is the creation of a dose distribution with a maximum in the target volume while minimizing the radiation impact in – and thereby protecting – the surrounding organs-at-risk. In the framework of virtual CT simulation, patients are positioned using dedicated positioning accessories (e.g. knee support, head holder etc.) on the CT table in a similar way as they will be positioned for the following fractionated treatment at the linear accelerator. In this process, it is essential to achieve high image quality, using a large Field of View (FoV) that covers the region of the tumor and the complete outline of the patient. Common practice is to use a 120 kV planning CT with 2 mm slice thickness as this setting is calibrated to convert Hounsfield Units (HU) to electron density of the tissue which is used for the RT planning treatment dose calculation for each patient.

In contrast to taking a standard 120 kV scan, Dual Energy (DE) CT requires that two scans are acquired at 80 kV (low kV) and 140 kV (high kV). The two scans at two different energies provide images with different HU values[1], depending on the tissue type. This information is then used to calculate monoenergetic ("DE Monoenergetic") images by projecting the measured HU values of the low and the high kV scan via dedicated known reference curves voxel by voxel to energy regions up to 190 keV. In many cases where metal is present, this leads to images with significantly reduced artifacts.

In this study, we first investigated the feasibility of implementing Dual Energy imaging in the Radiation Therapy setting by evaluating the influence of the DE Monoenergetic images on HU accuracy as well as the optimal parameter setting to optimize image quality for target delineation. In a second step, the usefulness of Dual Energy was evaluated on patients with metal implants about to undergo Radiation Therapy.

Technical evaluation based on a calibration phantom

Phantom measurements were performed to evaluate HU stability and noise in DE images, as a first validation that image quality of DE Monoenergetic images is adequate for RT planning. The tests were performed using a calibration phantom and a Siemens SOMATOM Definition AS 20 CT scanner. The phantom consisted of a carrier material equivalent to water and a set of inserts representing different tissue types (Figure 1). In order to minimize noise and maximize quality, all CT acquisitions were performed using the SAFIRE algorithm, a raw-data based iterative reconstruction (note: SAFIRE does not affect HU value accuracy).

Based on the 80 kV and 140 kV scan, the resulting DE Monoenergetic images have been evaluated regarding HU stability, noise and remaining contrast. The HU values of the inserts have been measured for various monoenergetic keV settings beginning from 40 keV to 180 keV. Based on HU stability results, the appropriate clinical range for RT was found to be above 80 keV. In this range, the measurements show generally stable HU behaviour for soft tissue as well as for lung (inhale and exhale) (figure 2). Only bone represented by two different densities showed a dependency on the keV setting as expected from its high effective atomic number (figure 3). A dedicated look-up table for the related keV setting can help to reduce the influence of this deviation but is not strictly required if bone structures are not part of the radiation field.

[1] A non-rigid registration ensures the exact matching of both image volumes in the case of single source Dual Energy with consecutive spiral scans.

Material equivalent	Rel. electron density
Lung (Inhale)	0,19
Lung (Exhale)	0,459
Adipose Tissue	0,952
Breast	0,976
Water	1
Muscle	1,043
Liver	1,052
Trabecular Bone	1,117
Dense Bone	1,512

Figure 1: Calibration phantom (left) with inserts representing various tissue equivalents.
The detailed tissue types and the related rel. electron densities are shown in the table (right).

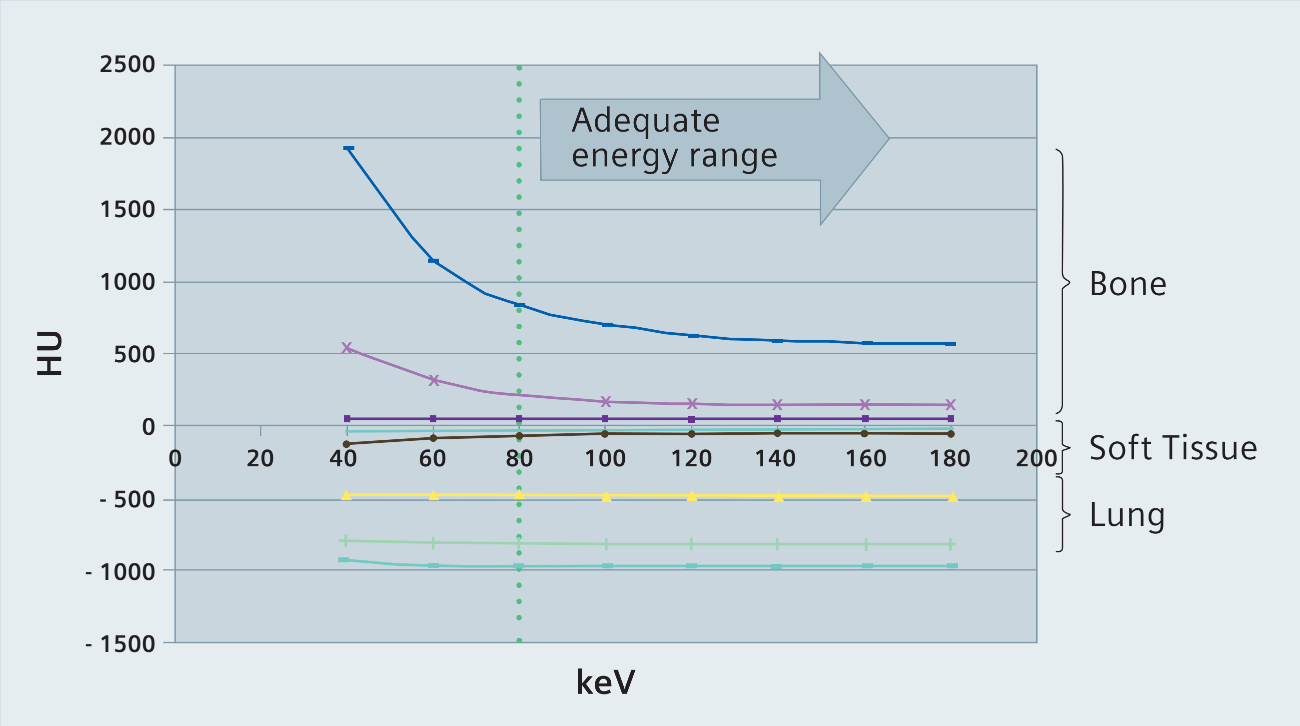

Figure 2: HU values for different tissue types at various keV settings. Above the 80 keV monoenergetic range, HU values can be considered to be stable for soft tissue and lung.

The level of noise is an important parameter in RT planning as it indicates the image quality and therefore the ability to reliably perform target delineation. Therefore, in addition to HU stability, the level of noise of DE Monoenergetic images was evaluated as a function of mAs and imaging dose.

The influence of dose on image quality using DE imaging is an important consideration to ensure that the clinical improvements obtained are not achieved at the expense of unacceptable dose levels. For this purpose three different DE scans mAs settings were chosen and the related noise for each setting was compared with the noise of the 120 kV scan (table 1).

The analysis of the DE Monoenergetic image noise behaviour (exemplary for the liver insert) showed a minimum noise for all mAs settings in the range of 70 keV. However, test measurements with the phantom showed, that a keV setting

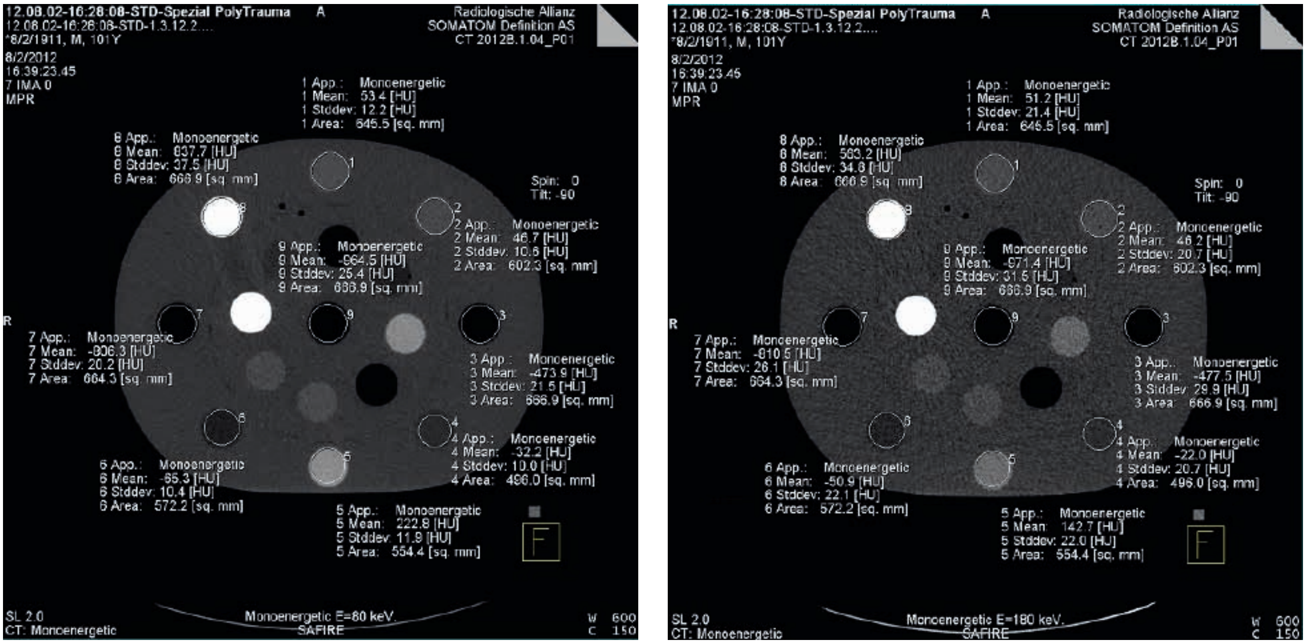

Figure 3: HU values for 80 keV (left) and 180 keV (right) DE Monoenergetic images. The HU of all ROIs remain stable, except in ROI number 5 representing trabecular bone and ROI number 8 representing dense bone.

Scan Pelvis	120 kV Single	CTDIvol	DE 80 kV	DE 140 kV	Total CTDIvol
Phantom w/o metal	223 mA	16,32 mGy	387 mA	73 mA	7,92 mGy + 7,88 mGy (“equivalent dose”)
			425 mA	81 mA	8,7 mGy + 9,3 mGy (“equivalent dose + ~15%”)
			612 mA	216 mA	12,53 mGy + 23,63 mGy (“maximum dose”)

Table 1: Comparison of the dose in single energy and Dual Energy CT scans in the pelvic region (see figure 4 for the corresponding noise behaviour). The same set of comparisons was performed for head/neck and thorax scan protocols.

of approximately 120 keV results in optimum image quality (best compromise of metal artifact reduction and signal to noise). For this keV setting a total Dual Energy dose of “standard single energy scan dose + 15%” should be applied to achieve an equivalent noise value in the image (figure 4).

Clinical scenario

Patients with ossary metastases or degenerations in the skeletal apparatus (joint abrasion) usually receive endoprosthesis consisting of metallic base material (e.g. titanium, steel...) as a stabilizing measure. These implants cause streaks and increased noise in the image with distorted density distribution in the neighbourhood of the implant as well as in more remote areas of the images. This leads to a more difficult delineation of anatomic structures during RT planning and incorrect calculated dose distributions.

This effect is demonstrated in figure 5 in a patient with an ossary metastatic renal cell carcinoma and the situation of a nail implant in the left femur with osteolytic metastases. Figure 6 shows an additional example of a patient with a PSA-recurrent prostate carcinoma and right-sided TEP (Total EndoProsthesis).

Usually the metal implants are at latest detected after the creation of the CT topogram when the virtual simulation procedure starts, and then need to be manually corrected. With a simple replacing of the standard planning CT protocol by the Dual Energy scan sequence, the two automatically acquired data sets at 80 kV and 140 kV are directly available for the *syngo*.CT Dual Energy Monoenergetic application.

The radiation therapist and the medical physicist adjust interactively the image via slider with the chosen DE Monoenergetic setting in order to achieve a CT image that shows best delineation of the target volume. If applicable for the next steps of dose calculation, the look-up table for the chosen DE Monoenergetic setting should be used for the treatment planning in case of dominating bone structures (figure 7). Note that the handling of multiple calibration curves is supported by most modern RT planning systems (e.g. Eclipse from Varian).

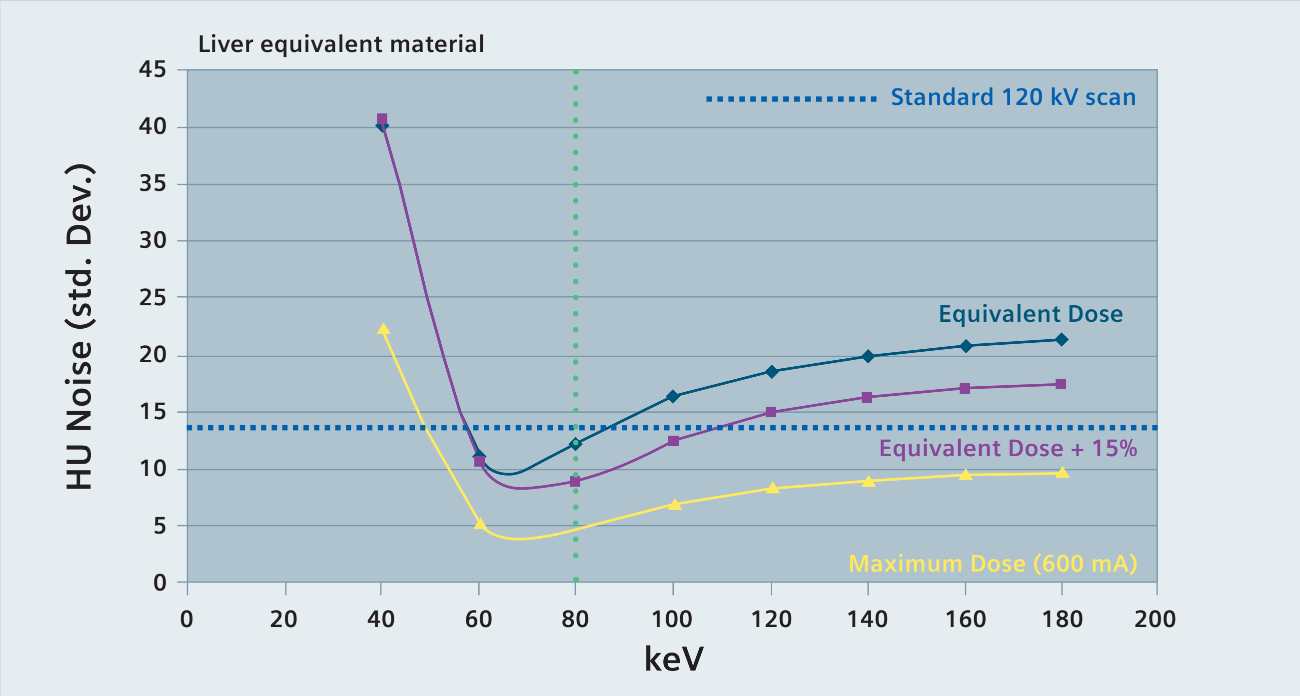

Figure 4: Noise behaviour (HU std. dev.) at different dose values relative to the standard dose at 120 kV (dashed line) for different monoenergetic keV settings. A total Dual Energy dose of "standard 120 kV single energy dose + 15%" leads to optimal noise values.

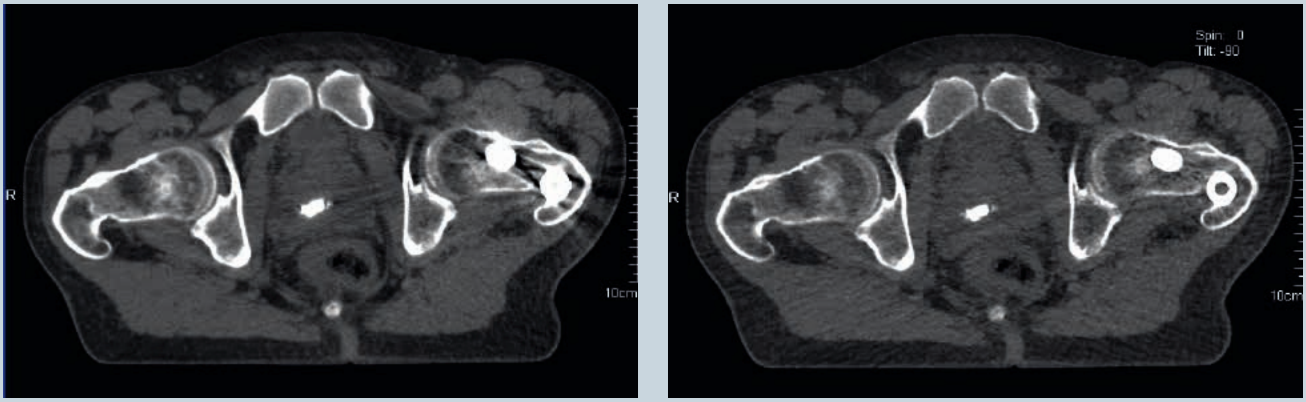

Figure 5: Left: Standard 120 kV CT scan of the left femur for RT planning. Right: 120 keV DE Monoenergetic image with a clear reduction of streak artifacts in the region of the target volume (left femur).

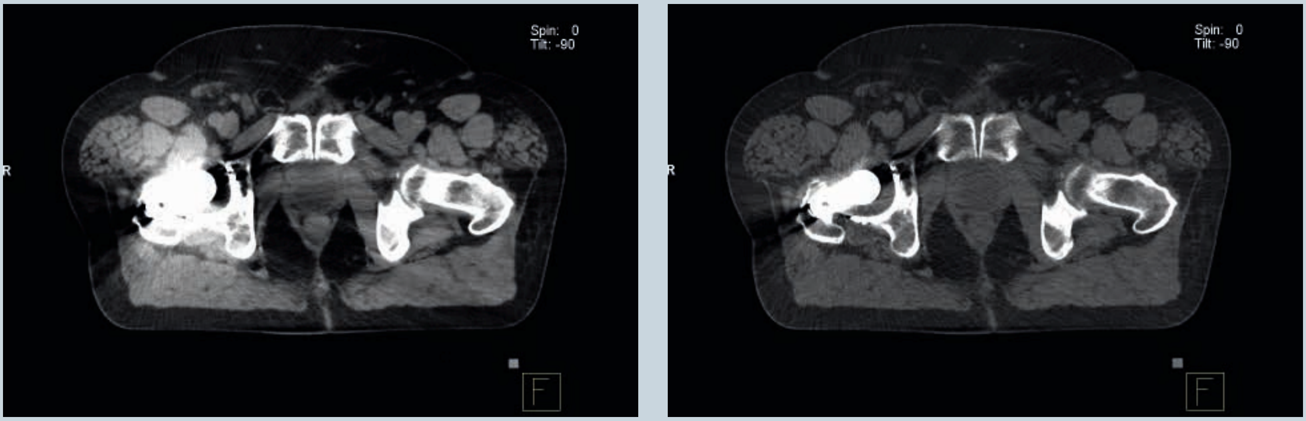

Figure 6: Left: standard 120 kV CT scan for RT planning of the prostate loge. Right: 120 keV DE Monoenergetic image with improved delineation of the target volume and significant reduction of artifact in the area around the TEP.

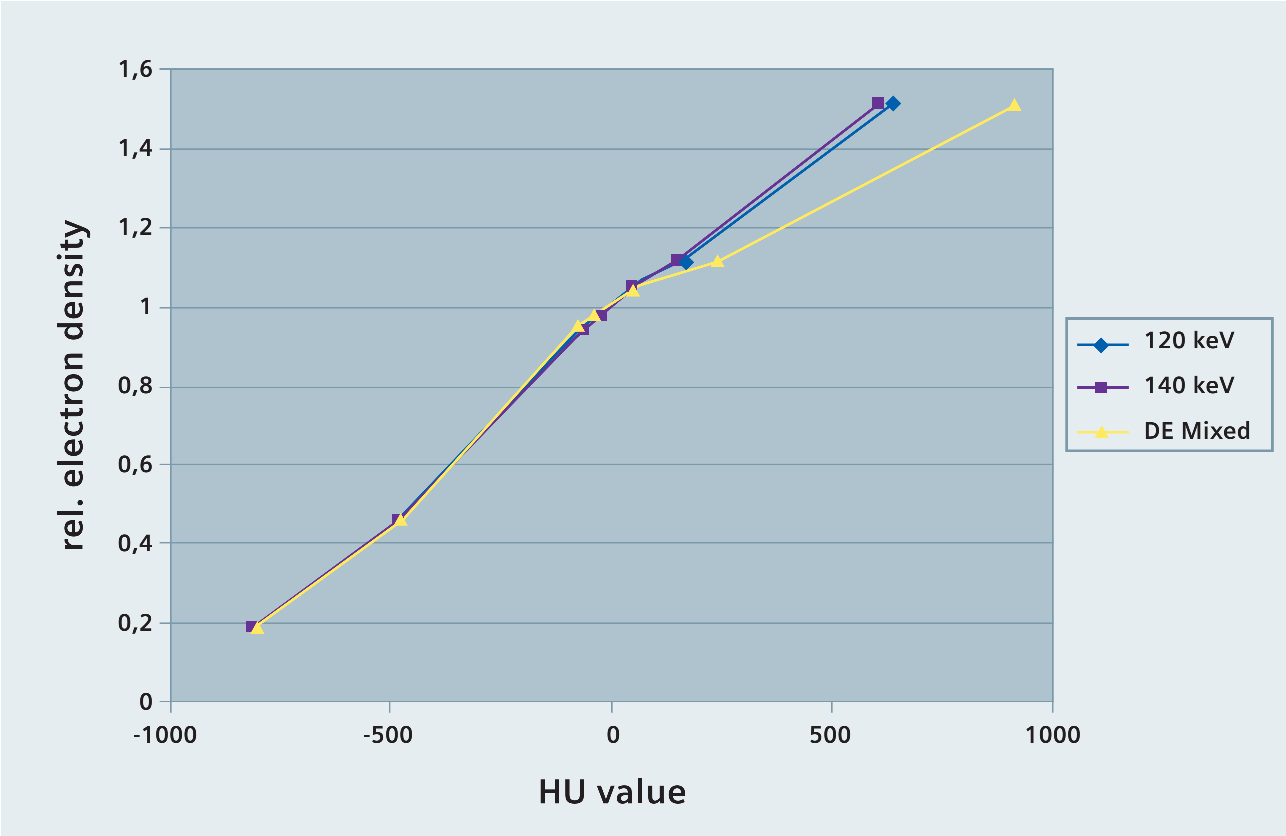

Figure 7: Calibration curves obtained with different keV monoenergetic settings (120 keV and 140 keV) compared with the standard curve of a DE mixed image (equivalent to 120 kV standard scan). A deviation is visible for the higher HU values which represent the bone equivalent inserts in the phantom, while soft tissue equivalents (< 200 HU) do not show a significant dependency on the energy setting.

In context of the target volume definition the improved visualization due to the reduction of metal artifacts can lead to better visualization and possibly to a reduction of margin. The correction of signal deletions close to the implant can improve delineation of the implant itself from the surrounding tissue. Usually treatment angles in the vicinity of the metal implant and its artifacts in the 120 kV scan are excluded from the plan. With the reduced artifacts in the DE image the physicist can choose these irradiation angles if desired. Figure 8 shows the results of a VMAT RapidArc planning with Eclipse for the prostate patient mentioned above underlining these benefits. On the left image the dose distribution of a standard 120 kV CT scan is shown. On the right, the 120 keV DE Monoenergetic CT image of the same patient scanned with Dual Energy is displayed. Figure 9 displays the application of Dual Energy CT for patients with tooth implants. This case shows the well known concave dose distribution of a head and neck case resulting from a RapidArc treatment planning with typical tooth artifacts. Figure 10 displays the benefits of DE for a patient with spine metastasis using the example of 3D conformal treatment planning. In all presented cases the variation of the attenuation coefficients or the HU values, respectively, is considered by using dedicated look-up tables of the related keV settings in Eclipse.

Finally, with reduced metal artifacts, additional advantages arise during virtual simulation. By using the DE Monoenergetic images, modern laser projection systems (e.g. PICTOR 3D from LAP for surface based RT information) may benefit from an improved patient contouring. Moreover, the anatomic definition of the isocenter close to implants can be optimized.

Conclusion

In this white paper, we demonstrated that Dual Energy CT scans reduce visibly metal artifacts while providing the HU stability and low noise or good image quality, necessary for treatment planning. The workflow is simple and benefits for Radiation Therapy are significant: in many cases manual assignment of HU is no longer needed resulting in significant time savings. Depending on the artifacts and the complexity of the contouring, time savings for the entire procedure of up to 30 minutes can be achieved. The time savings are due to the ability of skipping certain steps such as post re-segmentations, manual HU assignments and re-contouring of the body outlines. The improved image quality enables more options for these treatment plans which may now meet standard treatment goals and criteria. Since the introduction of Dual Energy scans, the Radiological Alliance centre is now using Dual Energy routinely for patients with metal implants.

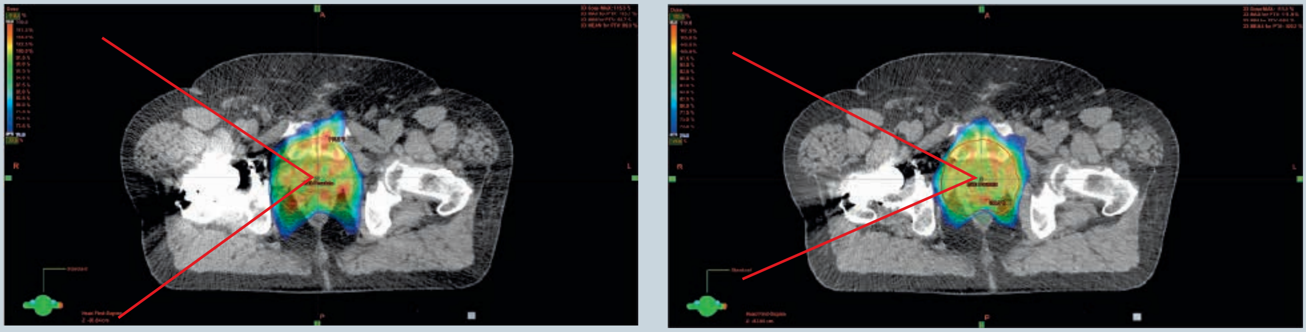

Figure 8: Display of the dose distribution with 6 MV photons in the Eclipse (Varian) planning system. The angle element between the red lines is not accessible for RapidArc optimization due to metal artifacts. Left side: the dose distribution of the 120 kV standard CT scan with an excluded angle of ~ 80°. Right side: 120 keV DE Monoenergetic leads to a significant reduction of the previously excluded segment.

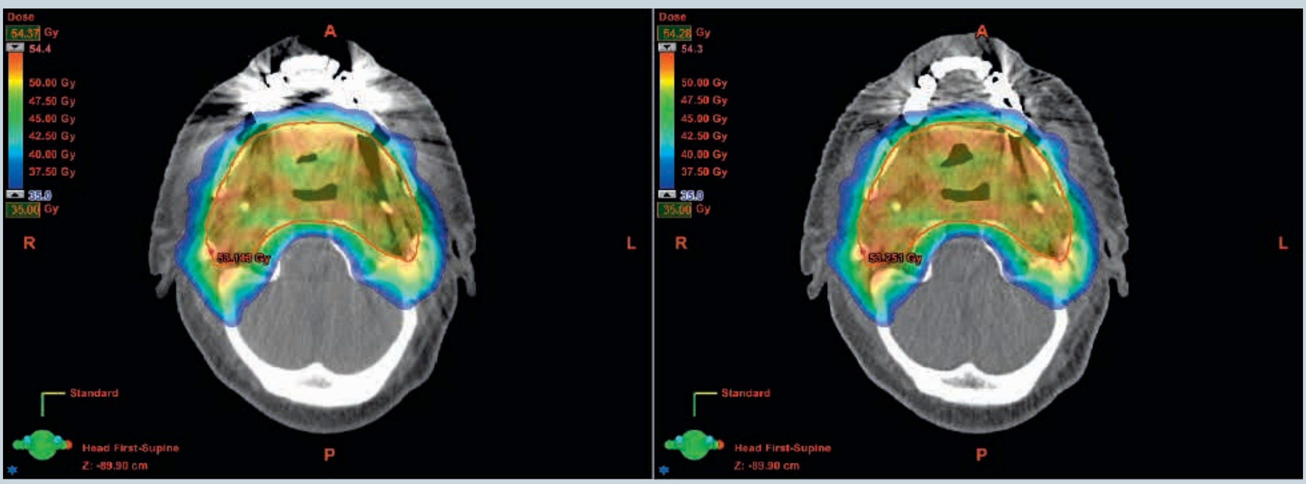

Figure 9: Display of the dose distribution of a head and neck case resulting from two full RapidArcs with 6 MV photons with typical tooth artifacts. Note that the plan optimization was done on the 120 keV DE study and than transferred to the 120 kV study. The plans for both studies were than finally calculated in the Eclipse treatment planning system. Due to the correct consideration of the calibration curve (see figure 7) on both datasets, the dose distribution is very similar almost identical.

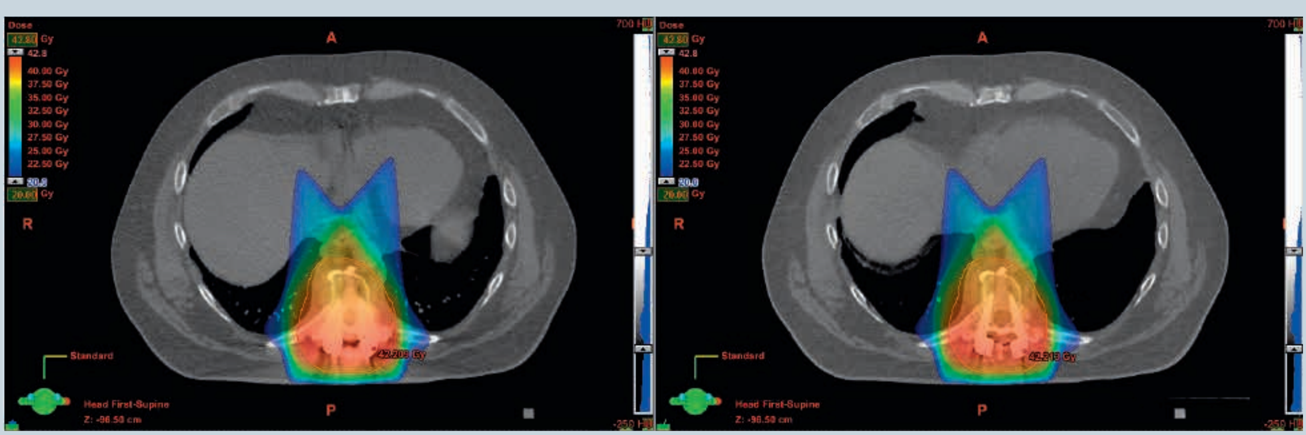

Figure 10: Display of the dose distribution of a patient with spine metastasis and metal stability support based on standard 120 kV scans (left) and 140 keV DE scans (right). The plan setup consists of four conformal 15 MV photon beams (ventro-dorsal opposing and dorso-lateral with virtual wedges). The dose differences between both studies are negligible when using the dedicated look-up table of the related keV setting, while the time for planning on the 140 keV DE scan was reduced (e.g. no manual HU assignment necessary).

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