

# DirectDensity cookbook

A guide to personalized CT imaging in RT

[siemens-healthineers.com/radiotherapy/ct-for-rt](https://siemens-healthineers.com/radiotherapy/ct-for-rt)



The scientific overlay is not that of the individual pictured and is not from a device of Siemens Healthineers. It was modified for better visualization.



For  
users of  
SOMATOM  
CT systems

## Foreword

Radiation oncology is experiencing growth in the use of personalized imaging for treatment planning and this trend has been embraced by physicists and physicians alike.

Clinical expert users have investigated and implemented novel image optimization technologies and we are pleased to be able to share these with you.

This cookbook is intended to propagate this information to users of DirectDensity on SOMATOM® CT systems. It presents a series of study protocols and practical tips and tricks from implementation to clinical routine, so that everyone can benefit from the clinical experts' experience. The information provided here can help your entire clinic to optimize workflows and provide the best imaging possible to cancer patients undergoing radiation therapy.

We look forward to hearing your feedback and suggestions, so that we at Siemens Healthineers can continue improving and helping you care for your patients.

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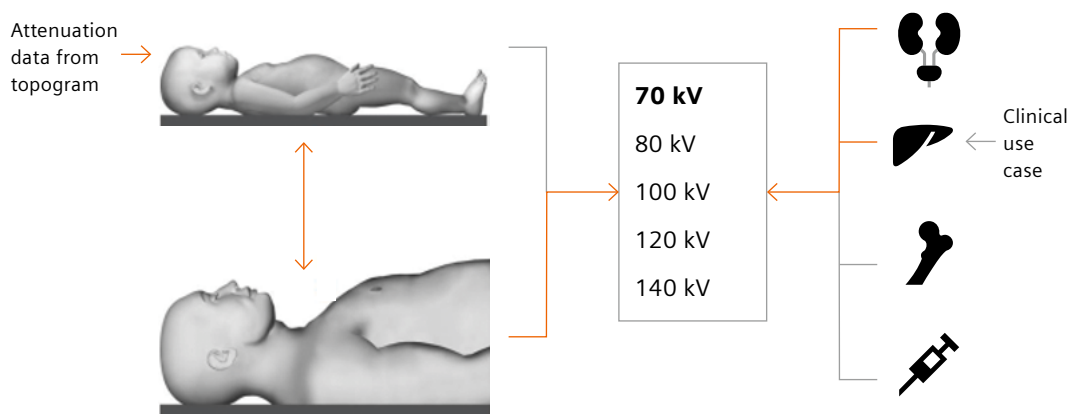
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# Benefits of image optimization and its challenges in RT

When performing a CT examination, the tube voltage is typically adjusted to the patient (e.g. body size, body part...) in order to maximize the image quality. In Radiation Therapy, CT images are transferred to the treatment planning system with two purposes, 1) contouring of target and 2) dose calculation where the CT parameters – in particular tube voltage – have been calibrated to convert the image intensity to an electron density. For the first purpose, an essential factor for CT image quality is the tube voltage expressed as the kV value. Siemens Healthineers has developed CARE kV, which allows you to automatically select optimal tube voltage and effective tube current to provide a predefined image quality level at the technically lowest possible radiation dose. Optimization is based on the patient-specific attenuation estimation from topogram data. Image quality is predefined by the quality ref. mAs value for a reference kV value for a standard patient. CARE kV can then adjust the actual effective mAs value depending on actual patient size and tube voltage. The objective is to obtain the same image quality as for the standard patient. Image quality is measured based on a CNR (contrast-to-noise ratio) relevant for a certain clinical use case. For radiation treatment planning, and especially for advanced therapies such as SRT, the technology can help increase confidence in contouring.



Ideally, the optimized kV setting suggested by CARE kV should be used in fully automated mode. However, due to the second purpose, but this would imply that the treatment planning is able to accept any tube voltage. Even when this is possible, it is usually very cumbersome and prone to error due to the necessity of having multiple calibration curves. This is why Siemens Healthineers has introduced DirectDensity.

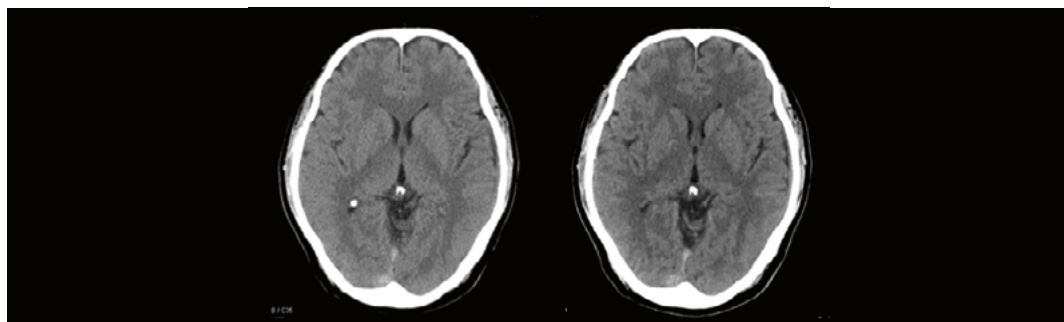
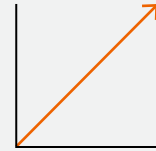


Image impression at 120 kV (left) and 100 kV (right) in a brain case with the same reconstruction parameters.

# Three key points about DirectDensity

## 1. What is DirectDensity?

CT images are transferred to the treatment planning system with two purposes, 1) contouring of target and 2) dose calculation. For the second purpose DirectDensity is an innovative technology that potentially enables the use of a single calibration curve for all tube voltage and beam filtration settings. It is available for selected CT and PET CT systems<sup>1</sup>.



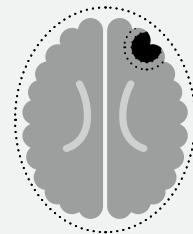
## 2. What does DirectDensity do?

DirectDensity removes the constraint of a fixed tube voltage setting and thereby enables the unconstrained use of tube voltage optimization such as for obese patients (with high tube voltage for low noise imaging), breast cancer patients (with low tube voltage for good CNR), pediatric patients (with low tube voltage for good CNR). It results in high-quality optimized images and a standardized workflow.

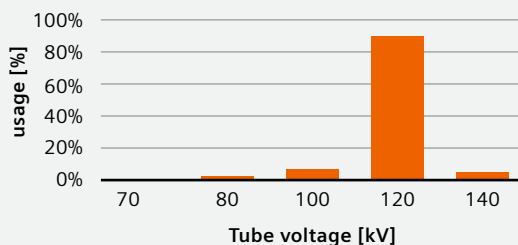


## 3. What are the potential benefits in RT?

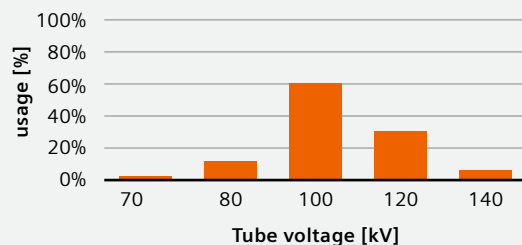
Contouring quality and consistency depends on image quality. DirectDensity removes the constraints on optimal tube voltage adaption by allowing CARE kV or the user to choose the optimal tube voltage for each patient.



Clinical kV usage before



Clinical kV usage after



Clinical kV usage before (left) and after (right) CARE kV implementation  
(Source: Based on customer usage measured with Siemens Utilization Management)

<sup>1</sup> Please contact your representative of Siemens Healthineers for further information about availability.

# Technical implementation

## Aim

The goal of this step is to define the scan protocols for algorithm validation.  
With the setup (example from Hospital Del Mar, Barcelona, Spain), the following five protocols were adapted to the DirectDensity (DD) workflow:

1) Brain 2) Head and Neck 3) Breast 4) Abdomen 5) Prostate

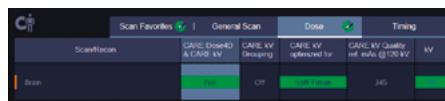
## Step 1: Protocol setup

Clinical area	Default protocol	Parameters to be changed	Important remarks
Brain	RT_Brain	1st recon: I30/Br38 <sup>1</sup> 2nd recon: F30/Sd40 (DD)	CARE Dose4D: <sup>2</sup> Yes CARE kV (semi mode/manual kV)
Head and Neck	RT_HeadNeck	1st recon: I30/Br38 2nd recon: F30/Sd40 (DD)	CARE Dose4D: Yes CARE kV (semi mode/manual kV)
Breast	RT_Breast	1st recon: I30/Br38 2nd recon: F30/Sd40 (DD)	CARE Dose4D: Yes CARE kV (semi mode/manual kV)
Abdomen	RT_Abdomen	1st recon: I30/Br38 2nd recon: F30/Sd40 (DD)	CARE Dose4D: Yes CARE kV (semi mode/manual kV)
Prostate	RT_Pelvis	1st recon: I30/Br38 2nd recon: F30/Sd40 (DD)	CARE Dose4D: Yes CARE kV (semi mode/manual kV)

## Tips: CARE kV

- CARE kV is a dose-saving mechanism that guarantees a predefined image quality.  
Semi mode or manual kV is required in order to evaluate CT values for different tube voltages.

SOMATOM go. platform



SOMATOM Definition AS Open/Confidence/Drive



"off" CARE Dose4D™ off and manual kV and mAs selection

"manual kV" CARE Dose4D on and CARE kV similar to "semi" mode of SOMARIS/7

"full" CARE Dose4D on and CARE kV similar to "auto" mode of SOMARIS/7

"full" doesn't allow you to select tube voltage to change. After the evaluation is complete, CARE kV may be set to full auto mode.

<sup>1</sup> Reconstruction kernels may vary based on software versions.

<sup>2</sup> CARE Dose4D is an automatic exposure control based on attenuation of the projection in real time.



## Step 2: Phantom scan setup

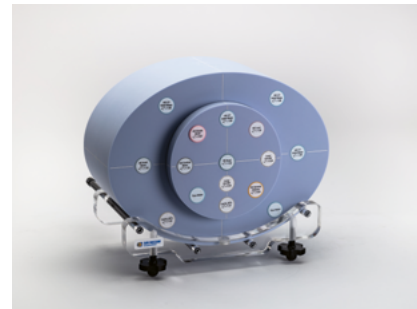
The aim of this step is to find out whether the DirectDensity algorithm provides a calibration curve proportional to electron density regardless of the acquisition conditions. To do this, the Advanced Electron Density Phantom from Sun Nuclear was used. Acquisitions are performed using both the small and the large phantom (this allows you to check how the patient thickness affects the Hounsfield units). The complete set of images acquired for calibration is composed of four series for each tube voltage setting with two different reconstructions (standard reconstruction and DirectDensity reconstruction) for two different phantoms (small and large phantom).

### Calibration phantom

Various calibration phantoms are available on the market. We used the Advanced Electron Density Phantom from Sun Nuclear, featuring Gammex® technology<sup>1</sup> to evaluate DirectDensity for this cookbook.

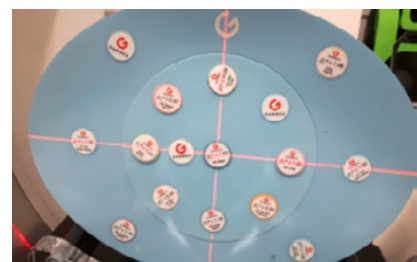
The features of this phantom are as follows:

- Adherence to ICRU-44 and ICRP material performance
- Expanded phantom size for wide-beam systems that can be used for CBCT as this phantom is thicker than the previous version
- Inserts include Air, LN-300 Lung, LN-450 Lung, HE General Adipose, HE Breast 50:50, HE Solid Water, Water, HE Brain, HE Liver, HE Inner Bone, 30% CaCO<sub>3</sub>, 50% CaCO<sub>3</sub>, HE Cortical Bone



## Step 3: Acquisition for calibration phantom

- 1) Place a Gammex® phantom the large (Advanced Electron Density Phantom) on the table.
- 2) Adjust the position of the phantom to the center of the bore and align it with the scan axis (use gantry lasers and markings or distinct features of the phantom).
- 3) Select the **RT Abdomen protocol**.
- 4) Set up scan and make sure that the scan range is centered on the phantom.
- 5) Perform repeated scans for all the tube voltages (e.g., 80 kV, 100 kV, 120 kV, and 140 kV).
- 6) Repeat all the scans with the large phantom for:
  - Breast protocol,
  - Prostate protocol.
- 7) Repeat all the scans with the small phantom for:
  - Head and Neck protocol,
  - Brain protocol.



Positioning of the Advanced Electron Density Phantom from Sun Nuclear

<sup>1</sup> Gammex is a wholly owned subsidiary of Sun Nuclear Corporation. The Advanced Electron Density Phantom, Model 1467, is Siemens PN GA805810.

## Step 4: Image analysis

- 1) Open the series in the TPS to measure CT values.
- 2) Use the middle slice position of the Advanced Electron Density Phantom.
- 3) A 2 cm ROI is used on the center of each rod  
(make sure that the ROI does not cover the edge of the rod).

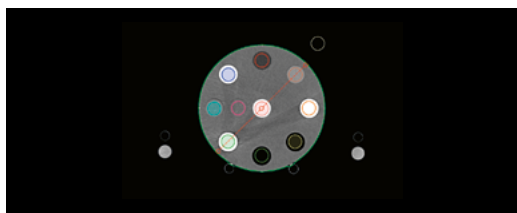


Image analysis using the large phantom (Breast, Abdomen, and Pelvis) and the small phantom (Brain and Head and Neck). The edge of the inserted material must be avoided, otherwise it introduces uncertainty to the CT values due to overshoot (orange arrows).

## Step 5: Calibration curve evaluation

- 1) Open Microsoft Excel, or an equivalent program. Enter your measured values into a table<sup>1</sup>.
- 2) The CT values for different materials using RT Abdomen and the large phantom are shown in the table below.
- 3) Calibration curves at different kV settings with and without DirectDensity are created as below.
- 4) Repeat this step for the different protocols (e.g. use the small phantom for the Brain protocol).

Material	Phantom certificate		CT value with standard reconstruction				CT value with DirectDensity			
	Relative physical density	Electron density	80 kV (HU)	100 kV (HU)	120 kV (HU)	140 kV (HU)	80 kV	100 kV	120 kV	140 kV
Air	0.000	0.000	-996.0	-997.1	-997.1	-997.5	-993.8	-995.4	-995.8	-996.8
LN-300 Lung	0.289	0.279	-698.6	-704.6	-705.8	-705.6	-697.2	-702.9	-703.9	-703.6
LN-450 Lung	0.462	0.447	-532.2	-538.3	-539.9	-539.6	-531.5	-537.5	-538.9	-538.7
HE General Adipose	0.962	0.951	-83.1	-73.5	-67.7	-64.2	-83.7	-74.4	-68.0	-64.5
HE Breast 50:50	0.983	0.969	-46.7	-38.4	-35.6	-33.5	-46.3	-40.1	-36.1	-33.2
HE Solid Water	1.022	0.998	6.6	6.2	4.2	5.5	3.9	2.7	3.1	4.7
Water	1.000	1.000	4.0	5.0	4.1	4.3	1.1	1.2	2.4	3.5
HE Brain	1.051	1.025	39.1	35.0	33.4	31.9	29.6	26.7	29.4	29.0
HE Liver	1.081	1.054	66.0	63.1	61.1	59.8	50.2	49.7	53.5	53.2
HE Inner Bone	1.214	1.164	413.2	347.1	305.7	278.9	166.8	171.8	170.9	168.9
30% CaCO <sub>3</sub>	1.332	1.268	621.3	528.7	474.5	438.5	245.0	255.6	260.0	259.7
50% CaCO <sub>3</sub>	1.559	1.462	1145.1	957.1	845.2	777.8	462.6	468.7	466.9	463.8
HE Cortical Bone	1.924	1.774	1876.7	1575.7	1390.3	1276.7	812.8	816.9	806.9	797.8

<sup>1</sup> These steps may also be achieved with RapidCHECK™ software from Sun Nuclear. Use RapidCHECK with the Advanced Electron Density Phantom to automatically locate and identify the material of each rod, and to streamline the CT-to-Electron Density table report.



Figure 1A: Calibration curves for RT Abdomen protocol with large phantom with standard reconstruction

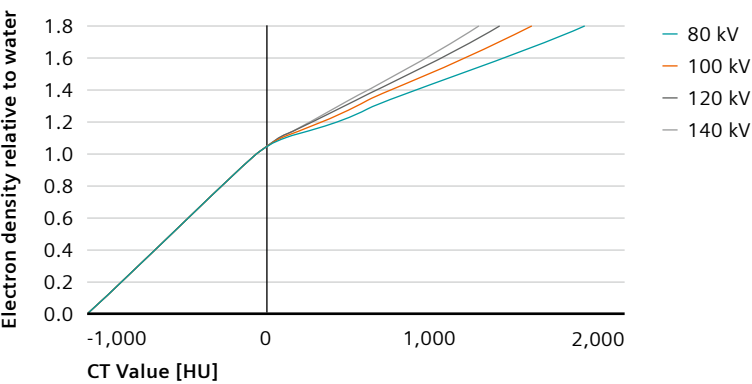
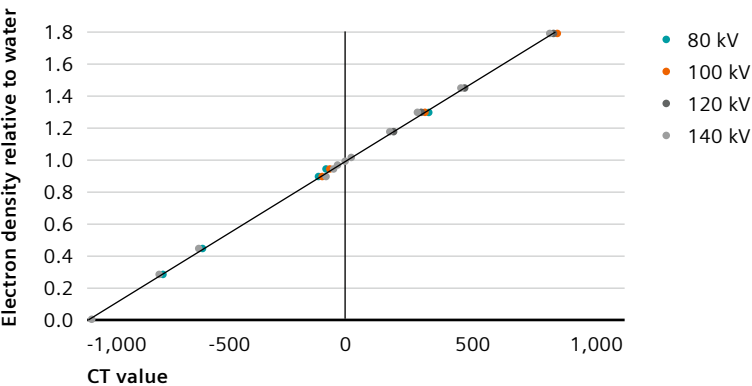


Figure 1B: Calibration curves with DirectDensity

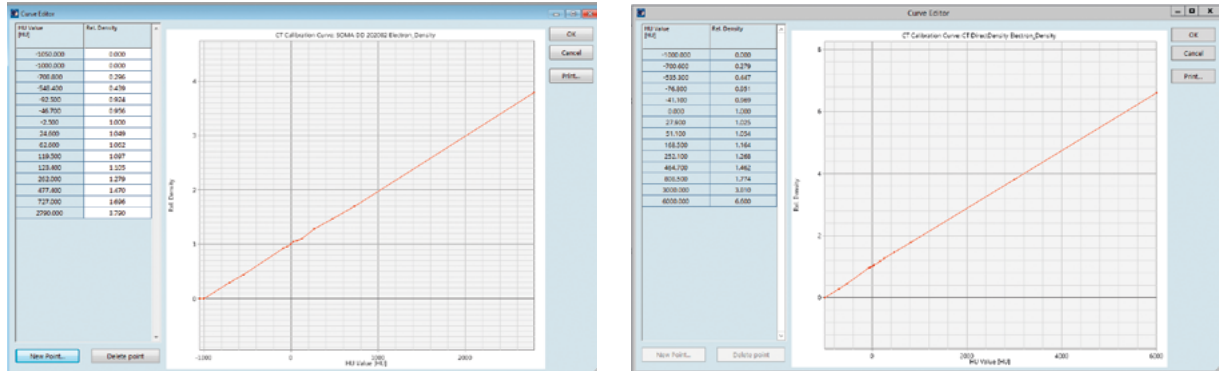


## Step 6: Calibration curve generation by averaging CT values obtained for different tube voltages

Calculate the average DirectDensity value by averaging the CT values obtained for different tube voltages for each material. In the example below, we took the average of all four protocols (Breast, Prostate with large phantom, and Head and Neck and Brain with small phantom).

Phantom certificate							
Material	Physical density	Electron density	80 kV DD image value	100 kV DD image value	120 kV DD image value	140 kV DD image value	Average DirectDensity image value
Air		0.000	-993.8	-995.4	-995.8	-996.8	-995.5
LN-300 Lung	0.289	0.279	-697.2	-702.9	-703.9	-703.6	-701.9
LN-450 Lung	0.462	0.447	-531.5	-537.5	-538.9	-538.7	-536.7
HE General Adipose	0.962	0.951	-83.7	-74.4	-68.0	-64.5	-72.7
HE Breast 50:50	0.983	0.969	-46.3	-40.1	-36.1	-33.2	-38.9
HE Solid Water	1.022	0.998	3.9	2.7	3.1	4.7	3.6
Water	1.000	1.000	1.1	1.2	2.4	3.5	2.0
HE Brain	1.051	1.025	29.6	26.7	29.4	29.0	28.7
HE Liver	1.081	1.054	50.2	49.7	53.5	53.2	51.7
HE Inner Bone	1.214	1.164	166.8	171.8	170.9	168.9	169.6
30% CaCO <sub>3</sub>	1.332	1.268	245.0	255.6	260.0	259.7	255.1
50% CaCO <sub>3</sub>	1.559	1.462	462.6	468.7	466.9	463.8	465.5
HE Cortical Bone	1.924	1.774	812.8	816.9	806.9	797.8	808.6

## Step 7: Commissioning (TPS<sup>1</sup> registration)



Calibration curve examples from Hospital Del Mar (left) and Nagoya University Hospital (right):  
The curve should be almost a straight line.

- 1) Log in to the TPS with an administrator (physicist) account
- 2) Go to calibration curve registration  
(e.g., Eclipse, beam configuration → Beam data → CT calibration)
- 3) Enter corresponding pairs of average DirectDensity image value and relative electron/physical density values (use air, LN-300 and 450, General Adipose, Breast 50:50, Liquid Water, Brain, Liver, Inner Bone, 30% CaCO<sub>3</sub>, 50% CaCO<sub>3</sub>, and Cortical Bone; enter CT value and relative density accordingly (see example above))
- 4) Extrapolation of the relative density to 6.0 might be optional (otherwise high-density single pixel can trigger a warning message that must be accepted every time)<sup>2</sup>
- 5) Check calibration curve – the line should be almost straight (see examples, left)
- 6) Save the calibration curve

### Tips for handling metal implants:

- 1) iMAR (iterative metal artifact reduction) is recommended to minimize metal artifacts in order to improve the certainty of dose calculation and contouring
- 2) Beam placement should not overlap with metal implants
- 3) To avoid warning messages due to high density, please insert 29768 for physical density (19.32 g/cm<sup>3</sup>)<sup>2</sup>

<sup>1</sup> Using Eclipse from Varian Medical Systems. Procedures may vary depending on the software versions or different TPS systems.

<sup>2</sup> Non-natural materials, for example metals and contrast agents like iodine, will decrease accuracy and – as with conventional CT images – can potentially lead to image artifacts.

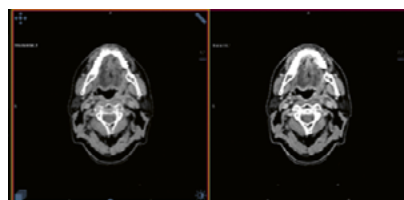
# Dosimetric evaluation

## Aim

On Figures (1A, 1B), we showed that varying the acquisition kV has almost no influence on the calibration curve when the DirectDensity reconstruction kernel is used. Before implementing in clinical routine, we recommend preliminary evaluation with a few clinical cases (e.g., four most important cancer sites, two cases each) in order to double check the dosimetric impact.

## Step 1: Series generation

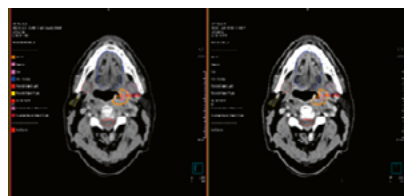
- 1) Head and Neck scan with CARE kV with full mode (in this case, 100 kV)<sup>1</sup>
- 2) Reconstruct two series, one with the standard reconstruction kernel, one with the DirectDensity kernel. If there are predefined scan protocols (see technical implementation step), two adequate reconstructions should already be defined. Reference data: 100 kV standard reconstruction. Comparison data: 100 kV with DirectDensity.
- 3) Export the two series to the TPS. In the TPS, make sure that the correct imaging device is selected (so that the TPS uses the appropriate calibration curve).



100 kV with DirectDensity (left), and without (right)

## Step 2: Dose calculation

- 1) Open the images in the TPS with standard reconstruction.
- 2) Contour organs at risk (OAR) and target.
- 3) Copy the contours to the DirectDensity reconstruction.
- 4) Calculate dose on standard reconstruction using Anisotropic Analytical Algorithm (AAA)<sup>2</sup> after optimizing a plan or setting some beams<sup>3</sup>.
- 5) Copy the plan and assign to the corresponding DirectDensity datasets.



100 kV with DirectDensity (left), and without (right)

<sup>1</sup> If 120 kV is required as reference, repeat the scan with 120 kV, and add reconstruction accordingly.

<sup>2</sup> Using Eclipse (Varian Medical Systems).

**Insert New Plan Sum**

**General**

Course ID:

Plan Sum ID:

Image:

OK  
Cancel  
Add New Plan

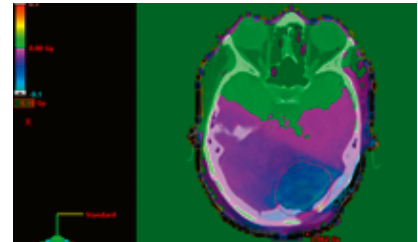
**Select plans to include in the sum**

	Course ID	Plan ID	Operation	Plan Weight	Structure Set	Target Volume	Primary Reference Point [Volume Type]	Presc. %	Fraction Dose [Gy]	Fractions	Total Dose [Gy]	Plan Normalization Mode
<input checked="" type="checkbox"/>	Estudi DD	MAMA D 120KV	+	1.00	SIMC1	TUMOR	TUMOR [TUMOR]	100.0	3.300	15	49.500	Plan Normalization Value: 100.00
<input checked="" type="checkbox"/>	Estudi DD	MAMA DD	-	1.00	DD F30 1...	TUMOR	TUMOR [TUMOR]	100.0	3.300	15	49.500	Plan Normalization Value: 100.00
<input type="checkbox"/>	Estudi DD	Mama_100KV	+	1.00	DD 130 1...	TUMOR	TUMOR [TUMOR]	100.0	3.300	15	49.500	Plan Normalization Value: 436.27

6) Calculate the new plan on the DirectDensity images and compare the dose with the reference plan (see example above)

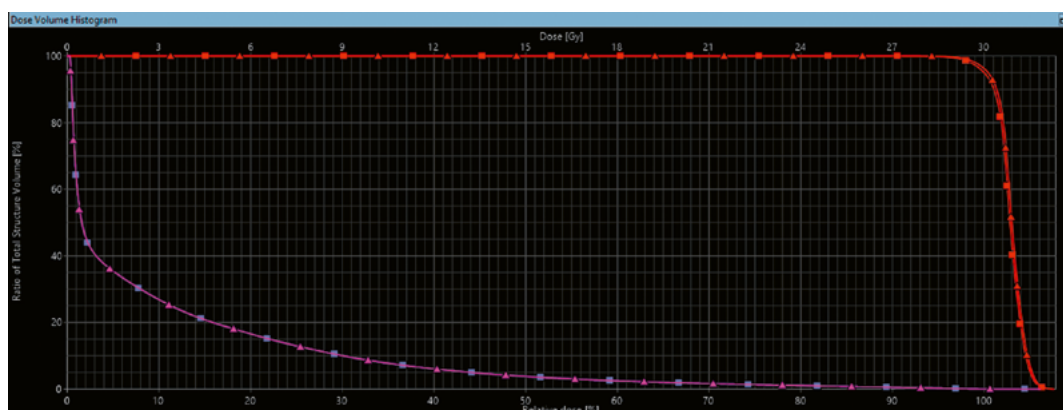
**Tip:**

- Please make sure that the corresponding calibration curve is selected when performing dose calculation.
- For simple analysis, the monitor units (MU) should be equal for both plans.



### Step 3: Dose-volume histograms (DVH) for maximum dose (Dmax), minimum dose (Dmin), and mean dose

The purpose of this step is to compare the DVH dose plan for standard reconstruction and DirectDensity reconstruction. We recommend comparing the Dmax, Dmin, and mean dose for each volume.



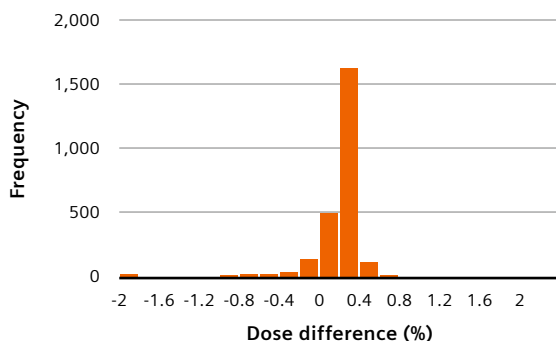
DVH comparison between DirectDensity reconstruction and standard reconstruction for following structures.  
Pink → PTV Red → Cervell

Show DVH	Structure	Approval Status	Plan	Course	Volume [cm³]	Dose Cover [%]	Sampling Cover [%]	Min Dose [%]	Max Dose [%]	Mean Dose [%]
<input checked="" type="checkbox"/>	AUX PTV+2cm	Approved	SNC 120	Estudi DirectD	300.8	100.0	100.1	1.5	107.7	46.3
<input checked="" type="checkbox"/>	AUX PTV+2cm	Unapproved	SNC DO 100KV	Estudi DirectD	298.2	100.0	100.0	1.6	107.8	46.5
<input checked="" type="checkbox"/>	CERVELL	Approved	SNC 120	Estudi DirectD	1143.8	100.0	100.0	0.3	106.2	9.6
<input checked="" type="checkbox"/>	CERVELL	Unapproved	SNC DO 100KV	Estudi DirectD	1137.5	100.0	100.0	0.3	106.3	9.6
<input checked="" type="checkbox"/>	PTV TUMOR SNC	Approved	SNC 120	Estudi DirectD	40.9	100.0	99.9	90.5	107.7	102.8
<input checked="" type="checkbox"/>	PTV TUMOR SNC	Unapproved	SNC DO 100KV	Estudi DirectD	40.4	100.0	99.9	90.6	107.8	103.0

Dose comparison in terms of Dmax, Dmin, and mean dose for each volume.

### Step 4: Voxel-by-voxel evaluation of dose distributions (optional)

For further evaluation, dose distributions of the plans based on the standard reconstruction and the DirectDensity reconstruction can be compared voxel by voxel. For example, you can use a dose difference frequency histogram. It provides a visualization of the distribution of dose differences between the two plans, as well as the mean and standard deviation of those differences. Within our evaluation, the DirectDensity-based plan shows a good alignment with the standard/conventional plan.



#### Tips:

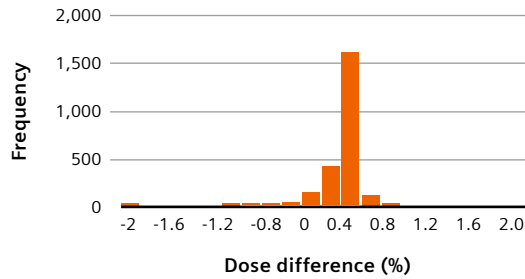
For voxel-by-voxel evaluation, dose distributions usually have to be exported from the TPS (usually in DICOM format) and then processed via suitable third-party applications capable of reading DICOM image data (e.g., ImageJ, MATLAB, Python/scipy-stack/pydicom, R). Be aware of any parameters such as dose-scaling factors; they can be found in the DICOM header.



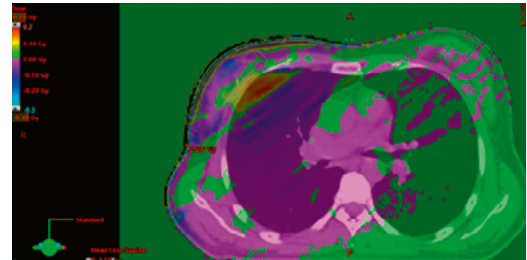
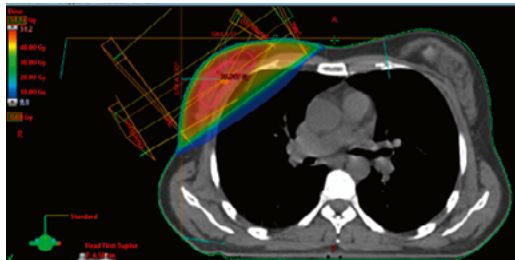
**Step 5: Check other clinical areas.**

**After looking into head and neck, we recommend applying the same procedure to other clinical areas.**

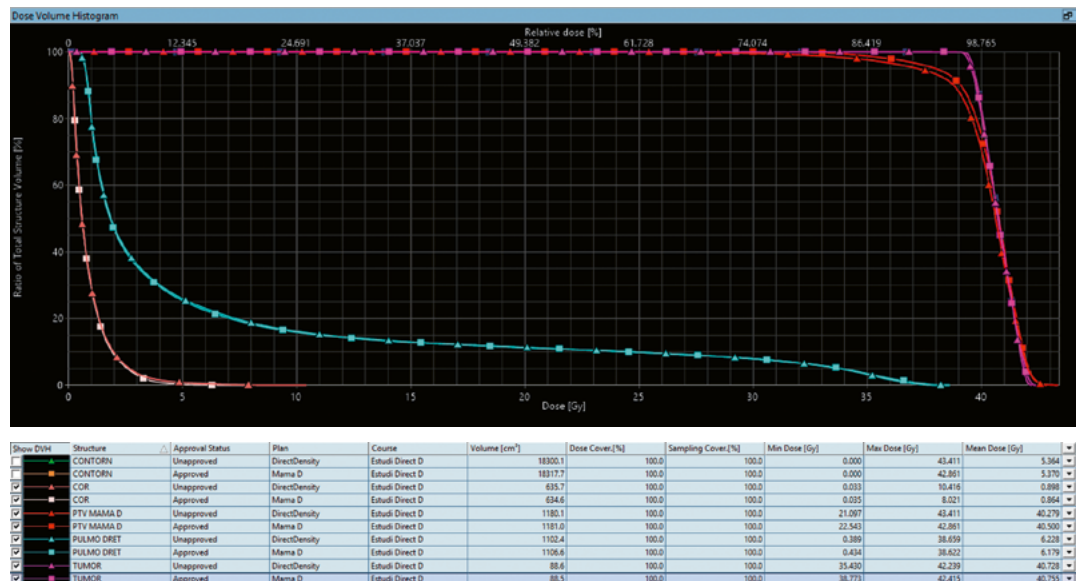
**Breast case**



Color scale from 0.2% to – 0.1% for dosimetric differences between 100 kV DirectDensity vs 100 kV standard reconstruction.



The total dose to the planning target volume of the breast was 49.5 Gy and there was only 0.08 Gy difference.



DVH evaluation (bottom right) for min, max, and average dose for OARs and PTV respectively.

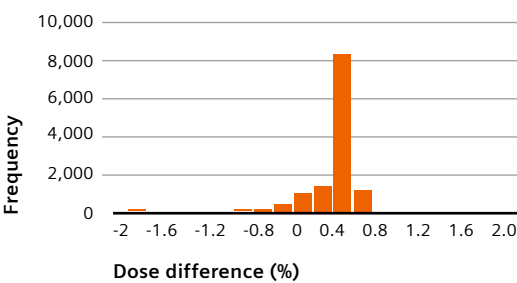
Red → PTV (Breast)

Pink → Tumor

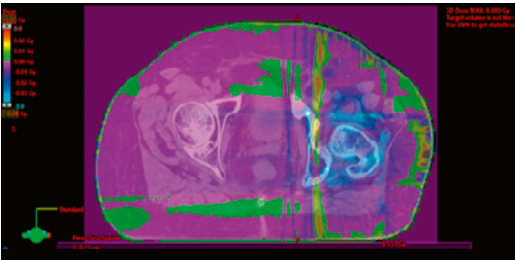
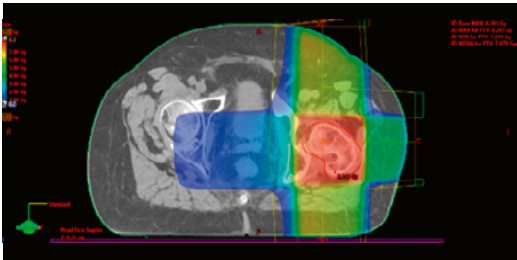
Light blue → Lung

Beige → Heart

Pelvis case



Color scale from 0.2% to – 0.1% for dosimetric differences between 140 kV DirectDensity vs 140 kV standard reconstruction.



The total dose to the planning target volume of the pelvic bone was 49.5 Gy and there was only 0.006 Gy difference.



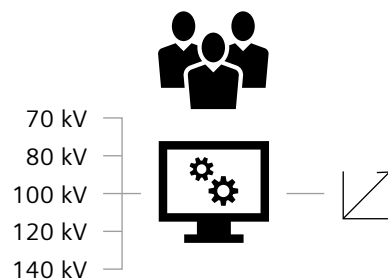
DVH evaluation (bottom right) for min, max, and average dose for OARs and PTV respectively.  
Red → PTV (Pelvis)      Yellow → Femoral head      Brown → Rectum

# DirectDensity workflow in clinical routine

## Aim

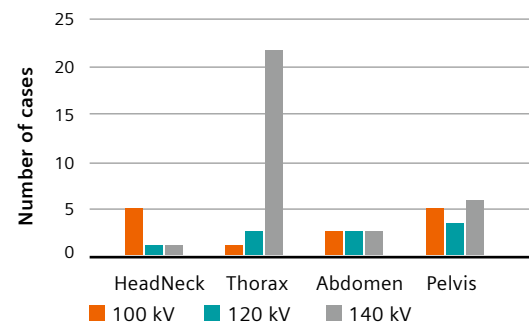
This section describes how DirectDensity can be used in clinical routine. After implementing the necessary changes in the treatment planning system and verifying on a few clinical cases that the algorithm performs as designed, it is important to also spend time understanding the implications of the implementation of DirectDensity on your clinical workflow.

## Step 1: Acquisition



Scan Favorites	General Scan	Dose	Timing
Scan/Recon	CARE Dose4D & CARE kV	CARE kV Grouping	CARE kV optimized for
Brain	Full	Off	Soft Tissue
			CARE kV Quality ref. mAs @120 kV
			345
			kV

Make sure that CARE kV is activated in native/soft tissue contrast mode. It automatically chooses the optimum kV based on attenuation data from the topogram



Clinical kV usage shows that different kVs are used depending on clinical area, patient, and cancer type. Also note that Thorax CTs are mostly performed with 140 kV when high attenuation area (shoulders) is included in planning CT to ensure sufficient contrast-to-noise level in upper lung area.

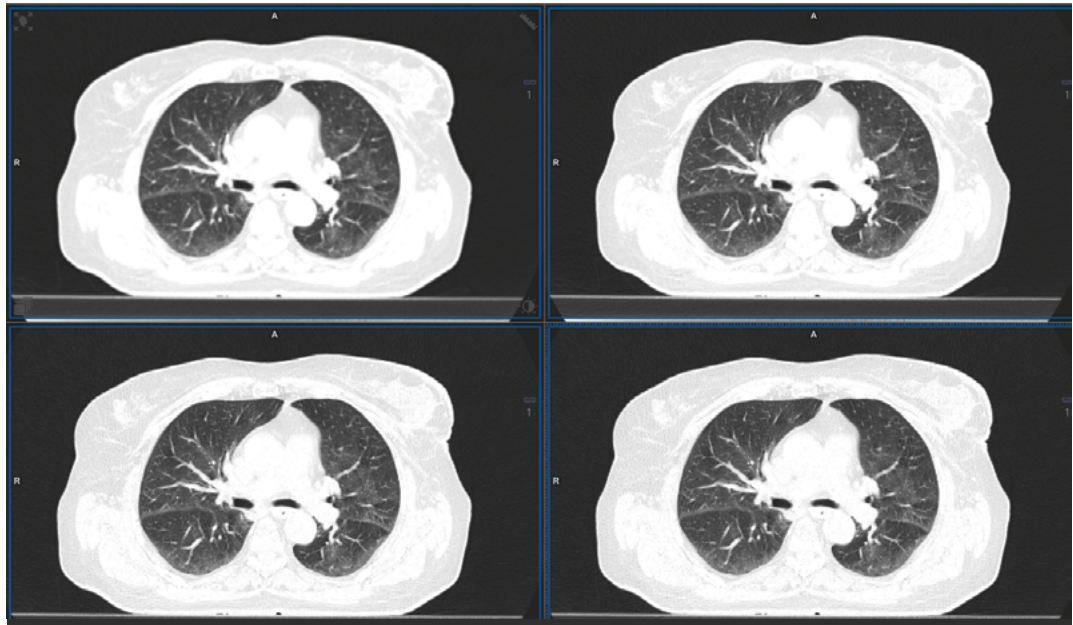
Distribution of the optimum kV as suggested by CARE kV' (Aichi Medical University Hospital city, Japan). Please note that Aichi Medical University Hospital chose to limit the CARE kV options to 100, 120, and 140kVp. If no constraints is set with CARE kV, the software would potentially pick 80kV or 70kV.

## Step 2: Reconstruction

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Two reconstructions are automatically performed as follows:

- 1) Standard reconstruction (for contouring)
- 2) DirectDensity reconstruction (for primary series)

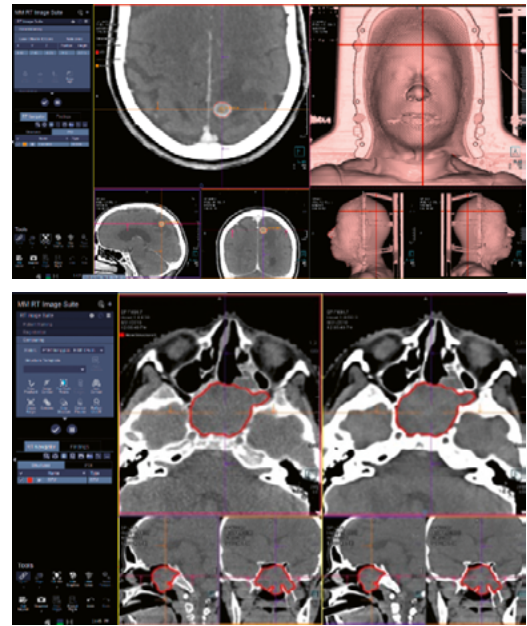


### Tips:

- SAFIRE (iterative reconstruction) can be applied routinely; iMAR (metal artefact reduction) or HD FOV (extended field of view) can be used if applicable.
- We recommend discussing optimal reconstruction parameters in your department. The example on the right shows different image impressions with different reconstruction kernels and windows.

### Step 3: Patient marking and contouring

- 1) Open the case with CT simulation software (e.g., Sim&GO or syngo.via RT Image Suite)
- 2) Perform patient marking on DirectDensity series
- 3) Make sure that DirectDensity series is selected as primary series (left)
- 4) Contour on standard reconstruction (right), which presents the optimal image quality/contrast.
- 5) Export following data to your Oncology Information System such as ARIA or your TPS:
  - DirectDensity reconstruction
  - Isocenter/reference point
  - OAR (organs-at-risk) contouring – CTV, PTV, ITV, etc.



DD

Optimal image

#### Tips:

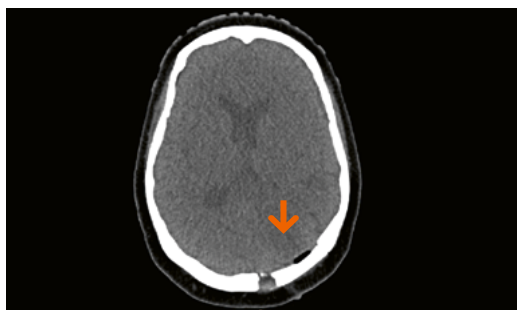
- To perform contouring on soft tissue, we recommend using a smooth kernel (such as I30 or Br38) designed for soft-tissue visualization.
- Low kV enables more contrast. The fast window feature can be used to automatically adapt the window to the acquisition kV in order to set the appropriate image impression for contouring (otherwise manual windowing needs to be applied).

### Step 4: Treatment planning

- 1) Select study to open the case in the TPS
- 2) Calibration curve for DirectDensity is automatically selected
- 3) Perform dose calculation in the TPS

## Clinical cases

120 kV



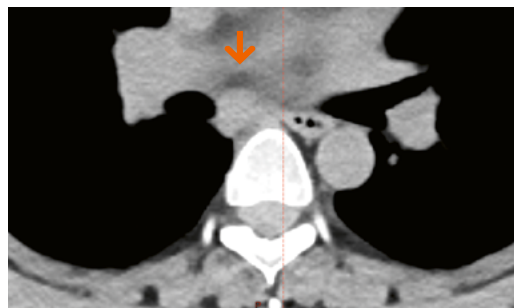
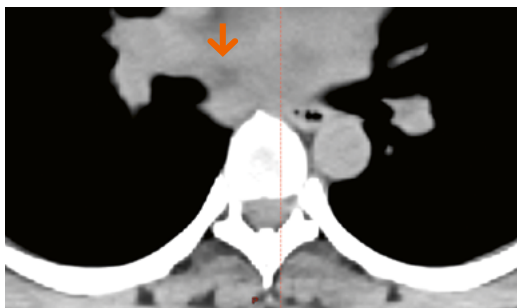
CARE kV



100 kV

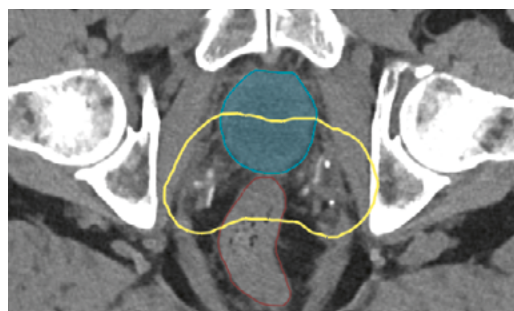
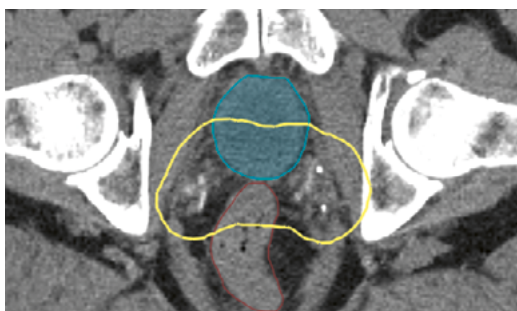
Comparison of images at 120 kV (left) and 100 kV (right) after brain surgery:  
The edema needs to be contoured as CTV for tumor bed radiotherapy.

After window level is optimized by radiation oncologist, 100 kV shows improved visualization of the edema for confident CTV contouring.



80 kV

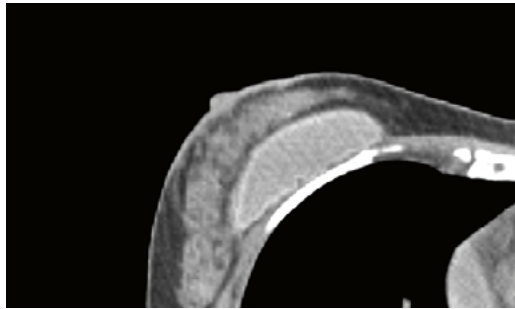
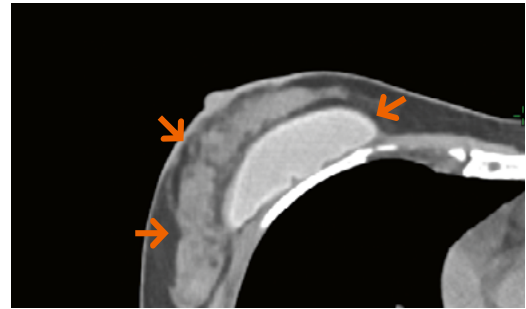
Lung cancer (paratracheal lymph node) case showing Thorax acquisition with 120 kV (left) and 80 kV (right): Compared to 120 kV, 80 kV provides better soft-tissue contrast.



140 kV

Radiotherapy case after prostatectomy: 140 kV (right) shows suitable level of image noise for PTV (tumor bed) compared to 120 kV (left) for obese patient.



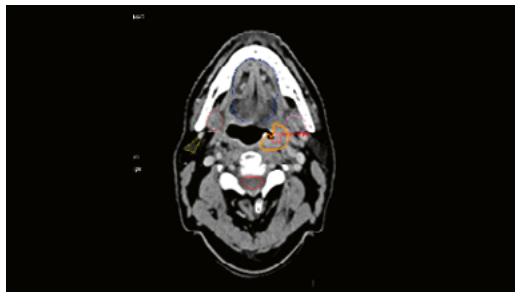
**120 kV****CARE kV**

100 kV

Radiotherapy after lumpectomy:

100 kV with SAFIRE provides a sufficient level of soft-tissue contrast in fat and mammary glands for breast contouring. As breast cancer patients have good survival rates, optimal dose (ideally dose reduction) is very important.

CARE kV provides a predefined CNR level for certain clinical tasks at the lowest possible dose, specific to the patient. DirectDensity enables the user to select any reconstruction kernel with advanced technique (e.g., SAFIRE)

**CARE kV**

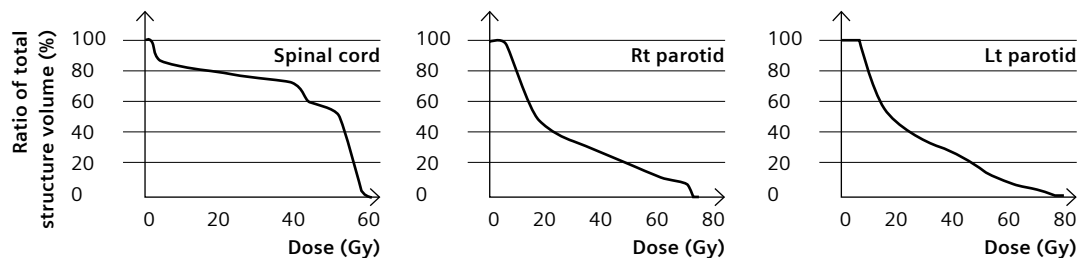
100 kV

100 kV with iodine contrast in head and neck cancer patient.

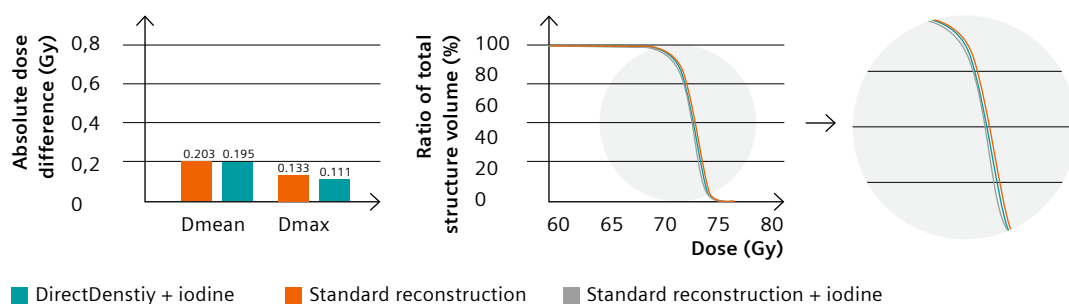
Some institutions have implemented DirectDensity with iodine contrast for dose calculation in head and neck cases. It potentially eliminates native scan and registration error between native and contrast scans.

**Tips: Influence of iodine contrast on dose calculation by using DirectDensity**

- In general, even without using DirectDensity, Choi et al [1] evaluated the influence of intravenous contrast agent on dose calculations of intensity-modulated radiation therapy plans for head and neck cancer and concluded that the difference between the doses calculated from the CTs with and without contrast agent enhancement was tolerably small. Using intravenous contrast agent could therefore be recommended for the planning of CT of head and neck IMRT without having to acquire a native non-enhanced scan for dose calculation.
- Minami et al [2] investigated the influence of iodine contrast with DirectDensity for six patients. The result shows that DVH for the OARs (spinal cord and parotids) are almost the same.



The ratio of the total structure volume (%) shows that DVH for the OARs (spinal cord, left parotid, and right parotid) are almost the same using DirectDensity with iodine, standard reconstruction, or standard reconstruction with iodine.



- DVH of the PTV (right) shows that:
  - standard reconstruction with iodine contrast results in a smaller dose than when using standard reconstruction without iodine contrast;
  - using iodine contrast on DirectDensity results in slightly lower influence than standard reconstruction with iodine contrast (absolute dose differences are shown on left).

# Conclusion

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Using one tube voltage setting is not ideal for all patients or all treatment sites. In general, lower tube voltage (e.g. kV setting) scans provide improved soft-tissue contrast. Patient size will also affect which kV setting is the most suitable. Larger patients, for instance, require a higher kV value to ensure sufficient signal. [3] To summarize, the DirectDensity workflow offers the following benefits:

- Improved soft-tissue contrast in low-kV imaging for brain, head and neck, lung, and breast cases
- DirectDensity provide images without compromising on individualization.
- DirectDensity images eliminate the need for tube voltage-dependent calibration.

DirectDensity is compatible with all other RT-relevant features – such as SAFIRE, iMAR, HD FOV, and 4D CT – making its clinical implementation easy and seamless. With minimal changes in the workflow, DirectDensity gives users another level of flexibility in image acquisition, and enables them to produce optimal and personalized images for each patient – without compromising the accuracy of the dose calculation.

This document provides helpful insights and step-by-step guidance for this procedure. We hope that these will help you successfully implement DirectDensity in your practice and that your patients will soon benefit from this innovative technology.

## References

**The creation of this cookbook was supported by the key experts from the healthcare industry:**

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[1] Choi Y, et al. et al, Influence of intravenous contrast agent on dose calculations of intensity modulated radiation therapy plans for head and neck cancer. *Radiother Oncol.* 2006;81(2):158-162.

[2] Yoshitaka M, et al. 32nd Annual Meeting of the Japanese society for Radiation Oncology. O21-4. 2019


[3] Nelson G, et al. Technical Note: The use of DirectDensity™ and dual-energy CT in the radiation oncology clinic. *J Appl Clin Med Phys.* 2019 Mar;20(3):125-131. doi: 10.1002/acm2.12546. Epub 2019 Mar 9. PMID: 30851087; PMCID: PMC6414137.

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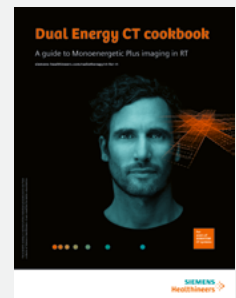
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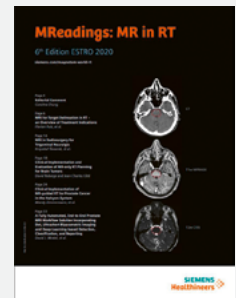
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## Notes

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