CT TECHNIQUE UPDATE: DOUBLE REDUCTION IN RADIATION DOSE AND CONTRAST AMOUNT

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- Double dose reduction

INTRODUCTION

Introduction - Unit

Exposure (조사선량)

- The amount of electrical charge produced by ionizing EM radiation per mass of air
- $X = \Delta Q / \Delta m$
- Units: Roentgens = $2.58 * 10^{-4}$ C/kg

Absorbed dose (흡수선량)

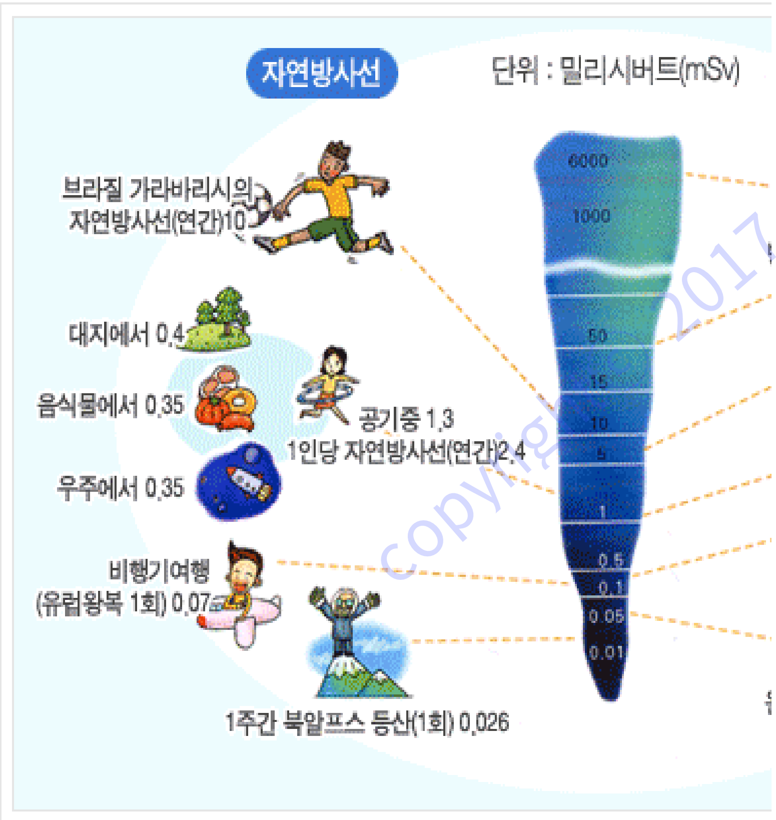
- The amount of energy that is actually absorbed at a specific point in space
- Units: Gray (1Gy = 1J/kg)

Effective dose (유효선량)

- Takes into account 1) types of radiation, 2) Radiosensitivity of the tissues
- Units: Sievert (Sv)

Definition – Low dose radiation

Low dose radiation : 100 mSv or less



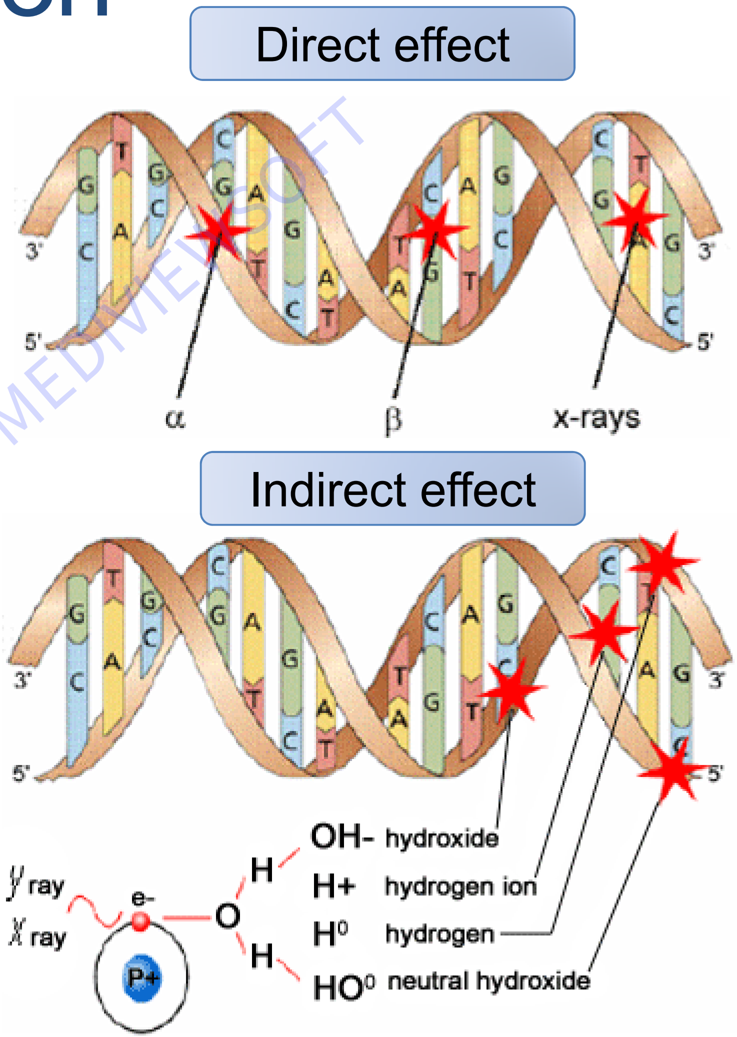
Imaging	Effective dose (mSv)
Chest x ray	0.02
Skull x ray	0.1
Lumbar spine	1.5
I.V. urogram	3
UGI	8
CT head	2
CT abdomen	8

http://www.fda.gov

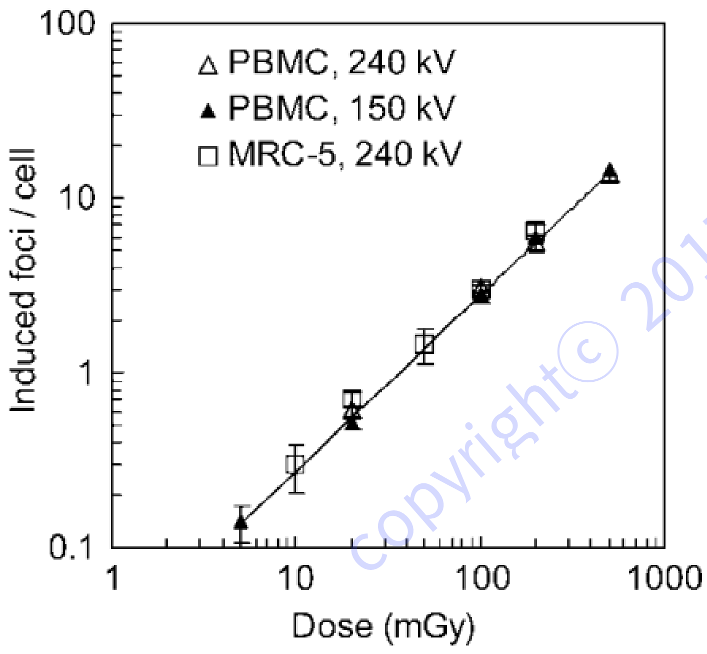
RADIATION DOSE REDUCTION: WHY?

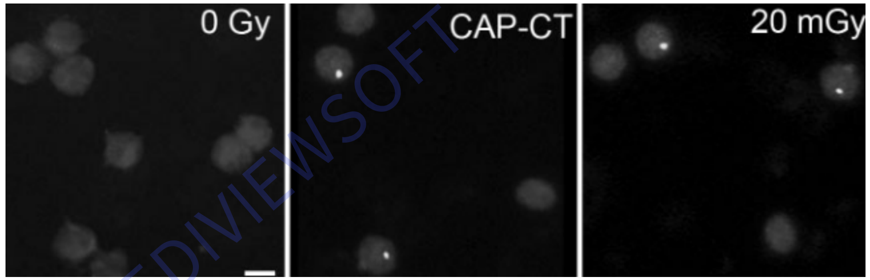
Response to Radiation

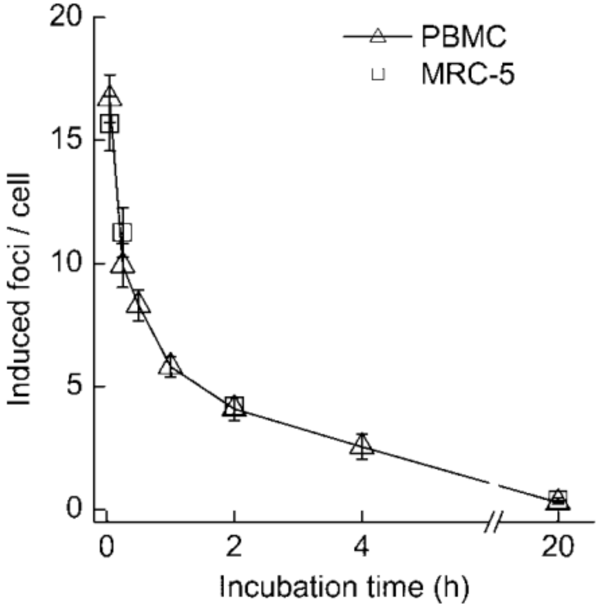
- Response to ionizing radiation
  - Damage such as breaking sugar phosphate backbones or base pairs of the DNA can occur either by direct or indirect action.



Response to Radiation

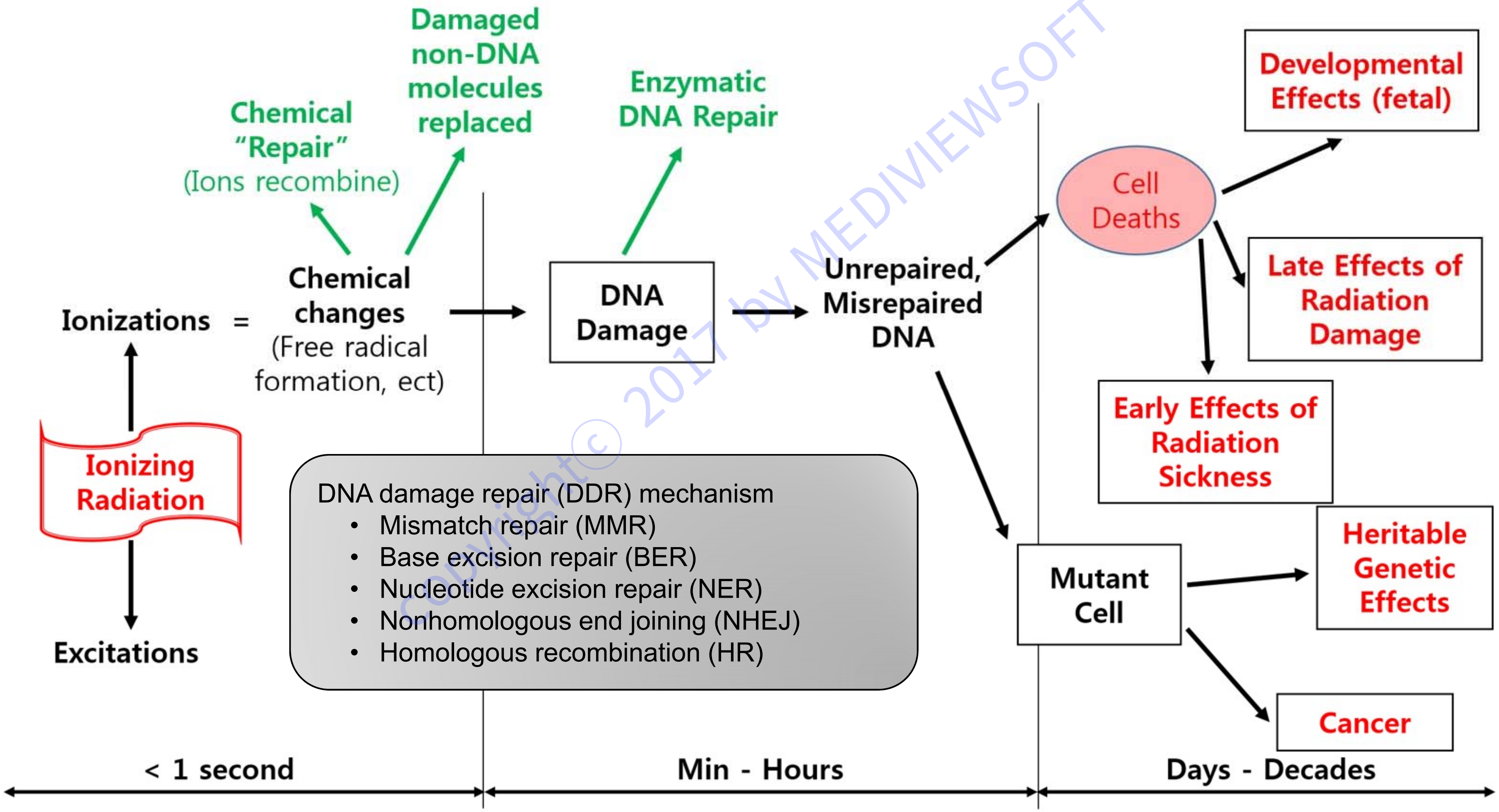






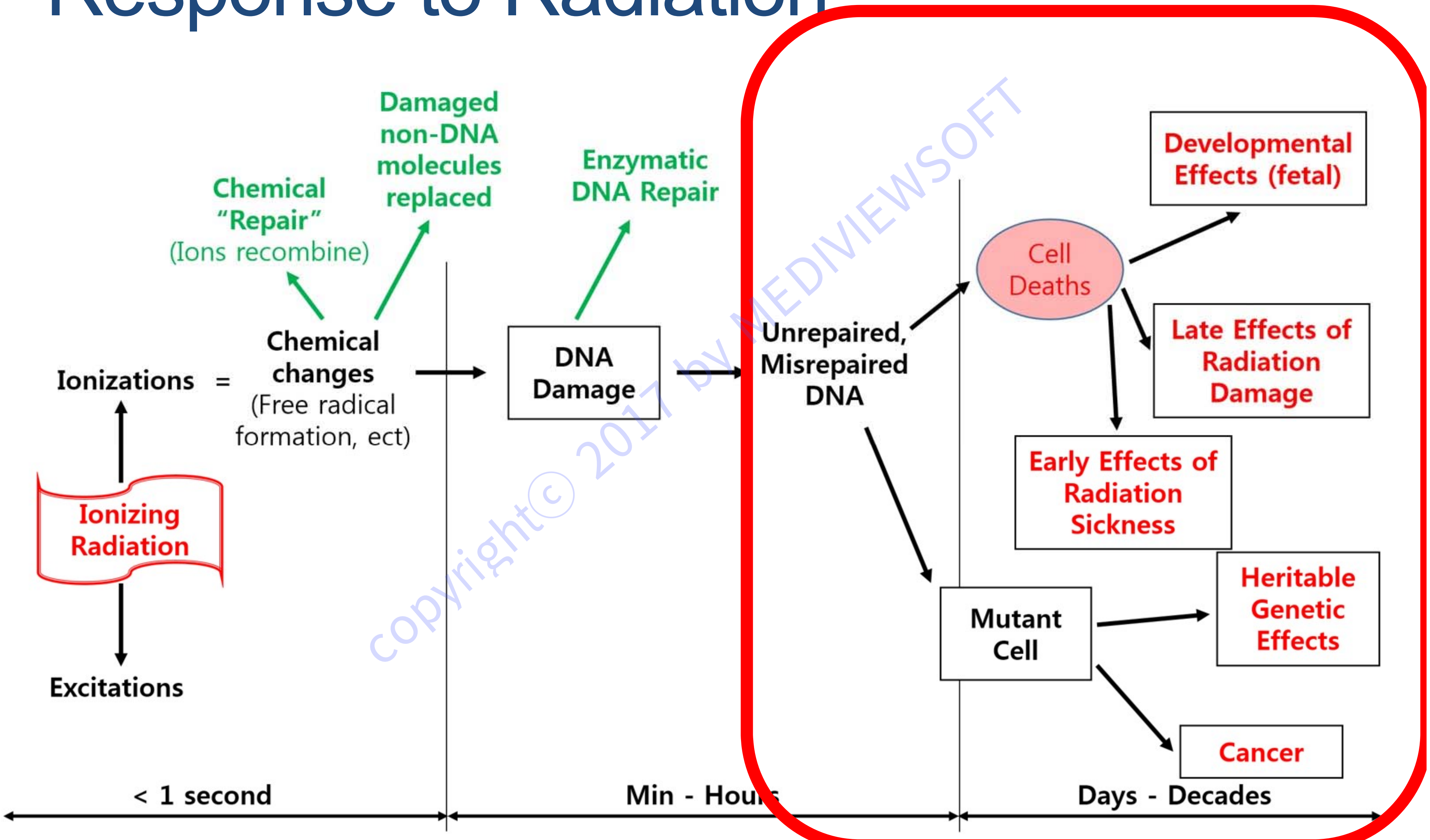
Rothkamm, Balroop et al. 2007

Response to Radiation



http://www.sigmaaldrich.com/technical-documents/articles/biofiles/dna-damage-and-repair.html

Response to Radiation



http://www.sigmaaldrich.com/technical-documents/articles/biofiles/dna-damage-and-repair.html

RADIATION DOSE REDUCTION: HOW?

Radiation dose reduction: How?

- Controllable parameters that contribute to radiation dose during CT
  - ∝ 1/Patients size
  - ∝ 1/Helical Pitch
  - ∝ Rotation Time
  - ∝ mA(s) (Photon fluence)
  - ∝ $(kVp)^{2.5\sim2.8}$ (Beam energy)

Hamberg et al. Radiology. 2003 Mar;226(3):762-72.
McNitt-Gray et al. Radiographics. 2002 Nov-Dec;22(6):1541-53.

Radiation dose reduction: How?

- Controllable parameters that contribute to radiation dose during CT
  - $\propto$ 1/Patients size
  - $\propto$ 1/Helical Pitch
  - $\propto$ Rotation Time
  - $\propto$ mA(s) (Photon fluence)
  - $\propto$ $(\mathrm{kVp})^{2.5\sim2.8}$ (Beam energy)

Hamberg et al. Radiology. 2003 Mar;226(3):762-72.
McNitt-Gray et al. Radiographics. 2002 Nov-Dec;22(6):1541-53.

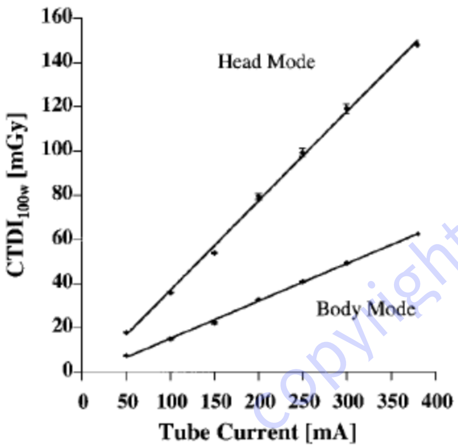
Controllable Parameters

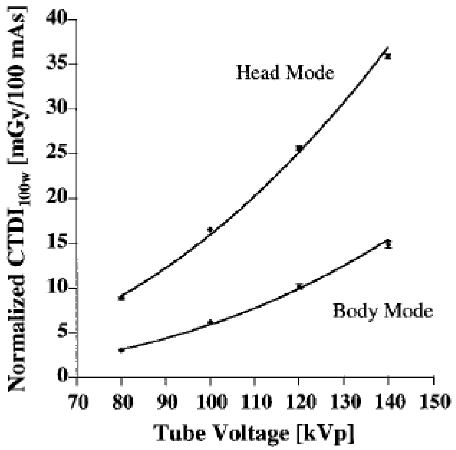
Tube current

- Dose ∝ Tube current
- Linear relationship

Tube voltage

- Dose ∝ Tube voltage
- Nonlinear relationship

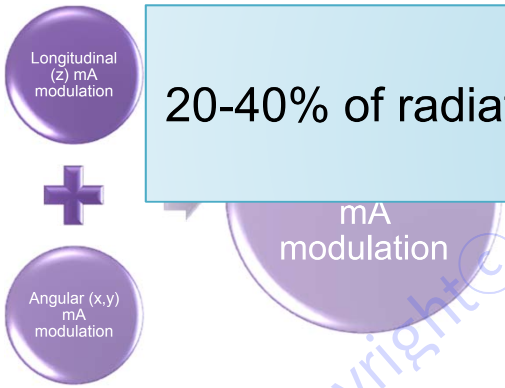




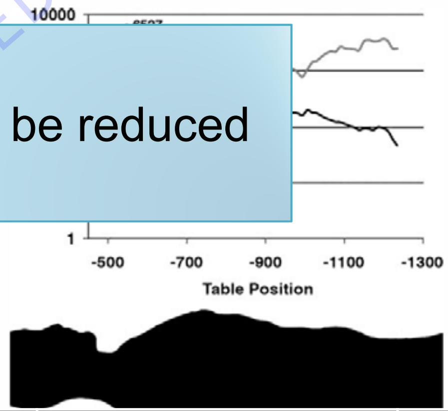
Hamberg et al. Radiology. 2003 Mar;226(3):762-72.

Automatic Exposure Control (AEC)

- Adjust mAs according to the patient’s attenuation for minimizing radiation exposure without deteriorating image quality



20-40% of radiation dose can be reduced



	GE	Philips	Simens	Toshiba
AEC software	Smart mA (XY) Auto mA (Z) ODM	DoseRight Automatic current selection (ACS) Z-DOM, 3D-DOM	CARE Dose 4D	SureExposure
Method for operator control of AEC	Noise Index	Reference Image	Reference mAs	Standard deviation

Lee CH. Radiographics 2008;28:1451-1459.
McCollough CH, Radiol Clin North Am 2009;47:27-40.

Adjusted kVp based on patient's size

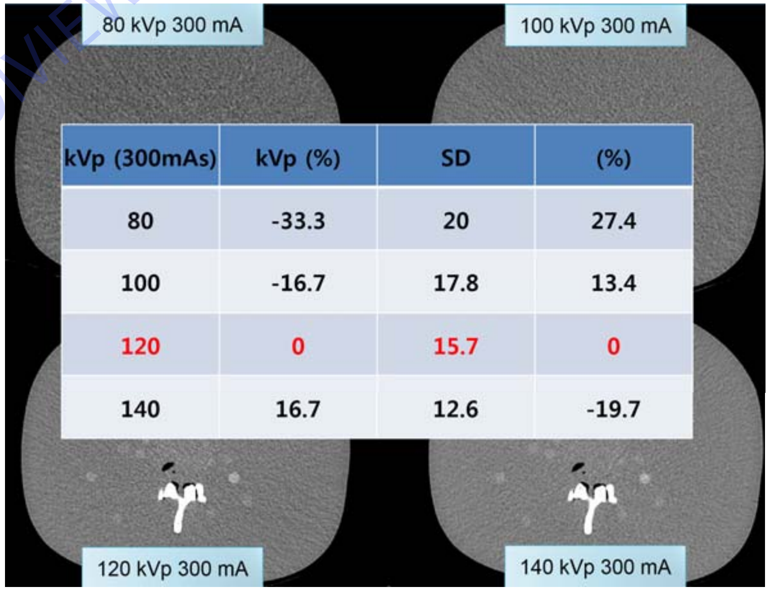
- ↓ radiation dose by adjusting kVp according to patient's size
- Care kV (Siemens), Assist kV(GE)
  - Automatic or semi-automatic kVp and corresponding mAs recommendations to each patients
- To maintain a specific image quality while minimizing dose

Additional 20-40% of radiation dose reduction

McCollough CH, Radiol Clin North Am 2009;47:27-40.

Adjusted kVp based on patient's size

- Drawbacks of low kVp protocol
  - 전반적인 Noise (SD)증가
    - higher absorption of low-energy photons by the patients.
    - Need ↑ mAs to maintain image noise
    - Iterative reconstruction 적용 필요

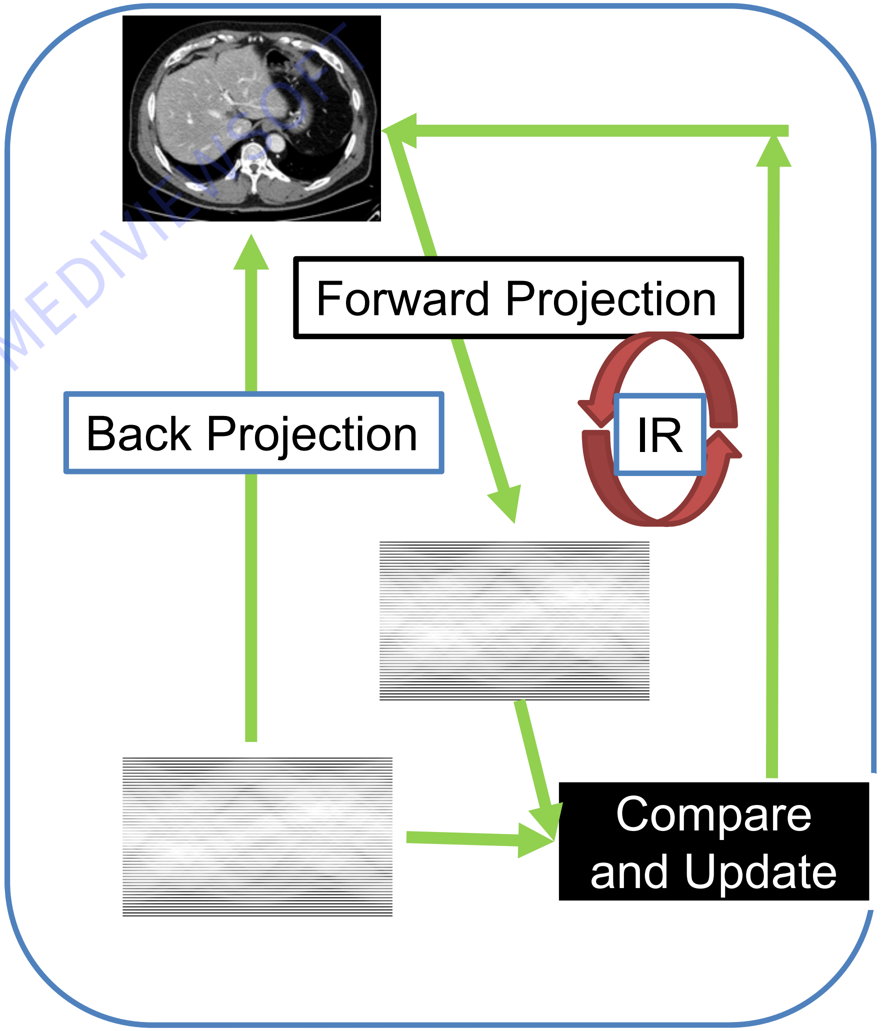


kVp (300mAs)	kVp (%)	SD	(%)
80	-33.3	20	27.4
100	-16.7	17.8	13.4
120	0	15.7	0
140	16.7	12.6	-19.7

McCollough CH, Radiographics. 2006 Mar-Apr;26(2):503-12

Iterative Reconstruction

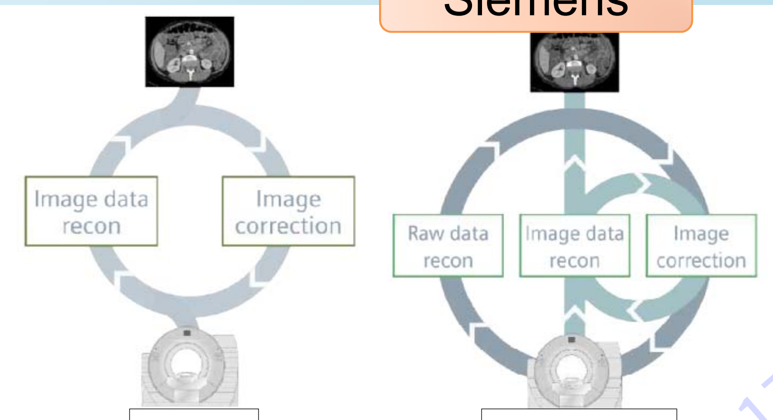
- Iterative reconstruction
  - Back projection: images are reconstructed from projection data
  - Forward projection: projection data are generated from images
  - Estimated projections are compared with the actual measured projections acquired by the CT
  - This comparison is then used to update the original estimate



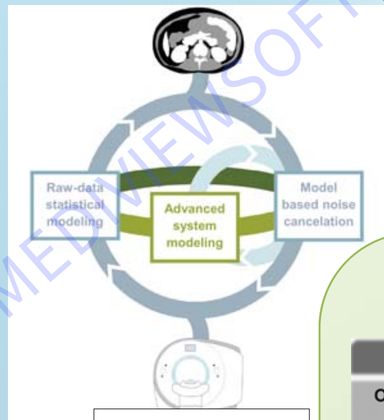
Nelson, R. C. J Cardiovasc Comput Tomogr. 2011 Sep-Oct;5(5):286-92.
Willemink, M. J.Eur Radiol. 2013 Jun;23(6):1623-31

Iterative Reconstruction

Siemens

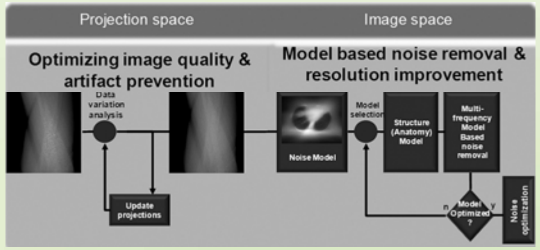


IRIS SAFIRE



ADMIRE

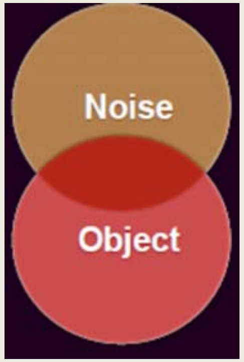
Philips



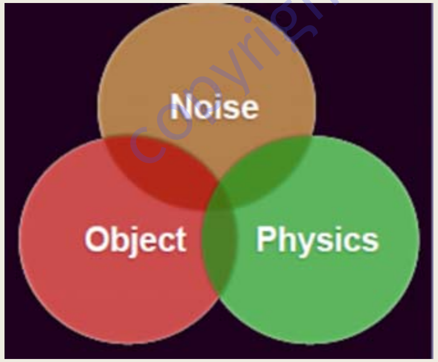
iDose^4

IMR Knowledge-Based Iterative Reconstruction Technique

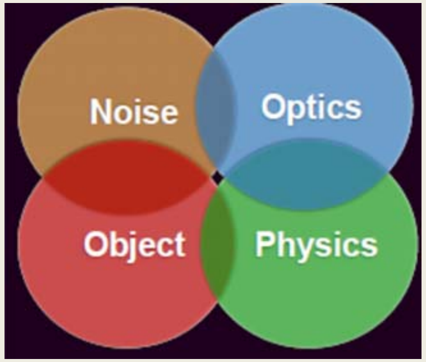
ASiR



ASiR-V



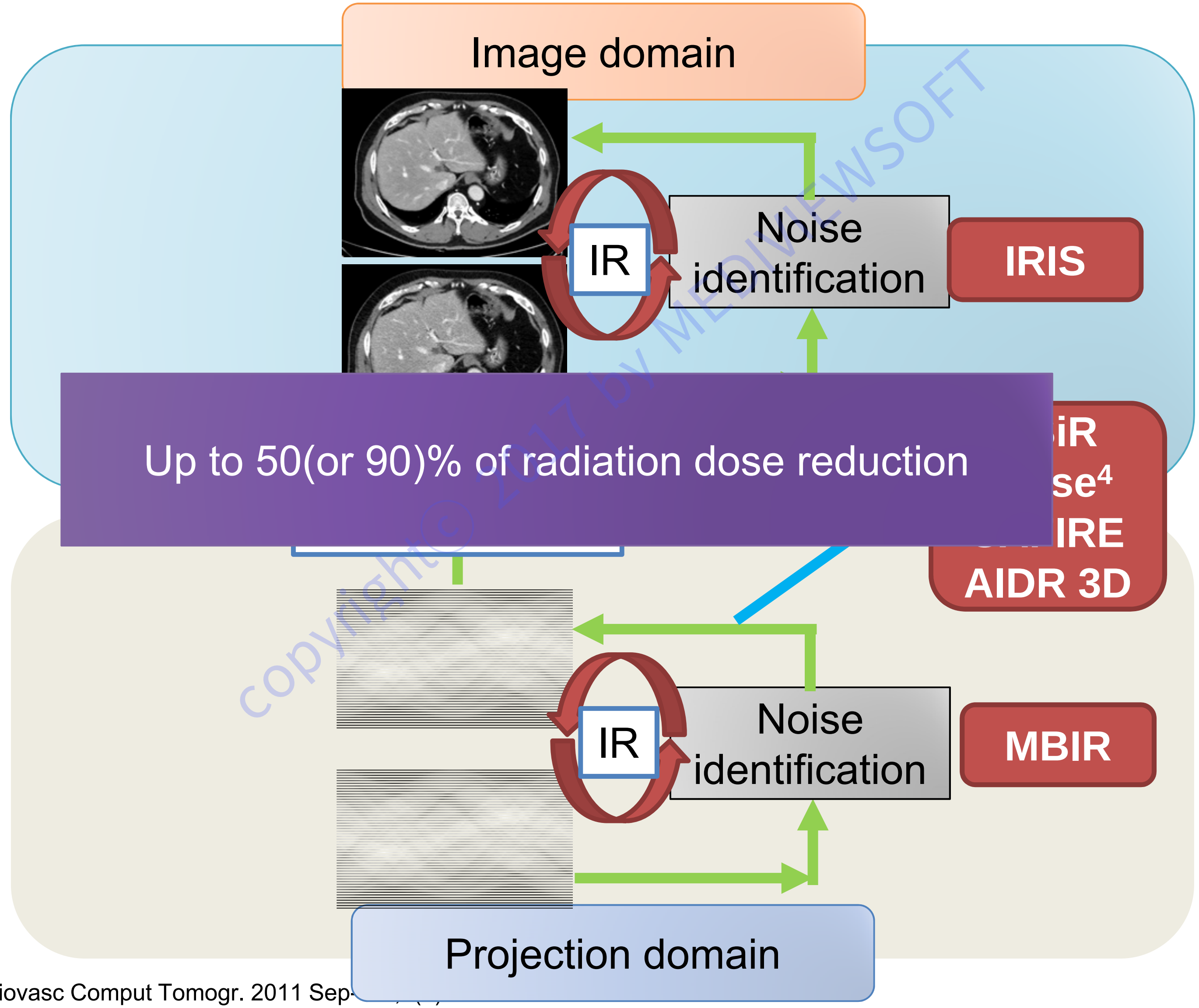
VEO



GE

White paper from Siemens, GE, Philips

Iterative Reconstruction



Nelson, R. C. J Cardiovasc Comput Tomogr. 2011 Sep

Iterative Reconstruction

- Disadvantages of IR
  - Need longer reconstruction times and higher computational power compared to FBP
  - Limitation in metal artifact reduction
  - Blotch, pixelated appearance of images
  - Decreasing low contrast resolution in strong IR setting

Khawaja,Pediatr Radiol. 2015 Jul;45(7):1046-55

Iterative Reconstruction

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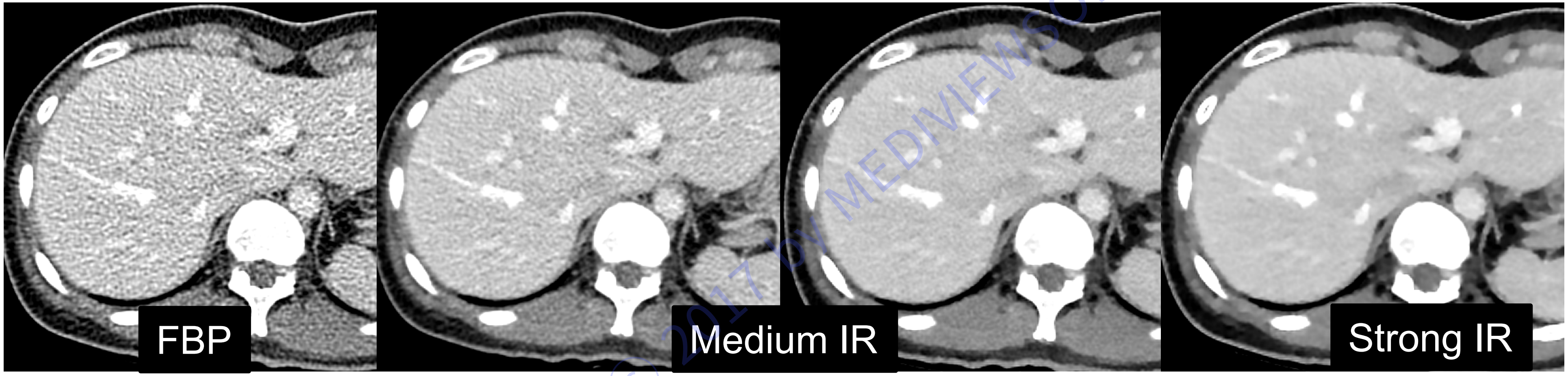
Iterative Reconstruction

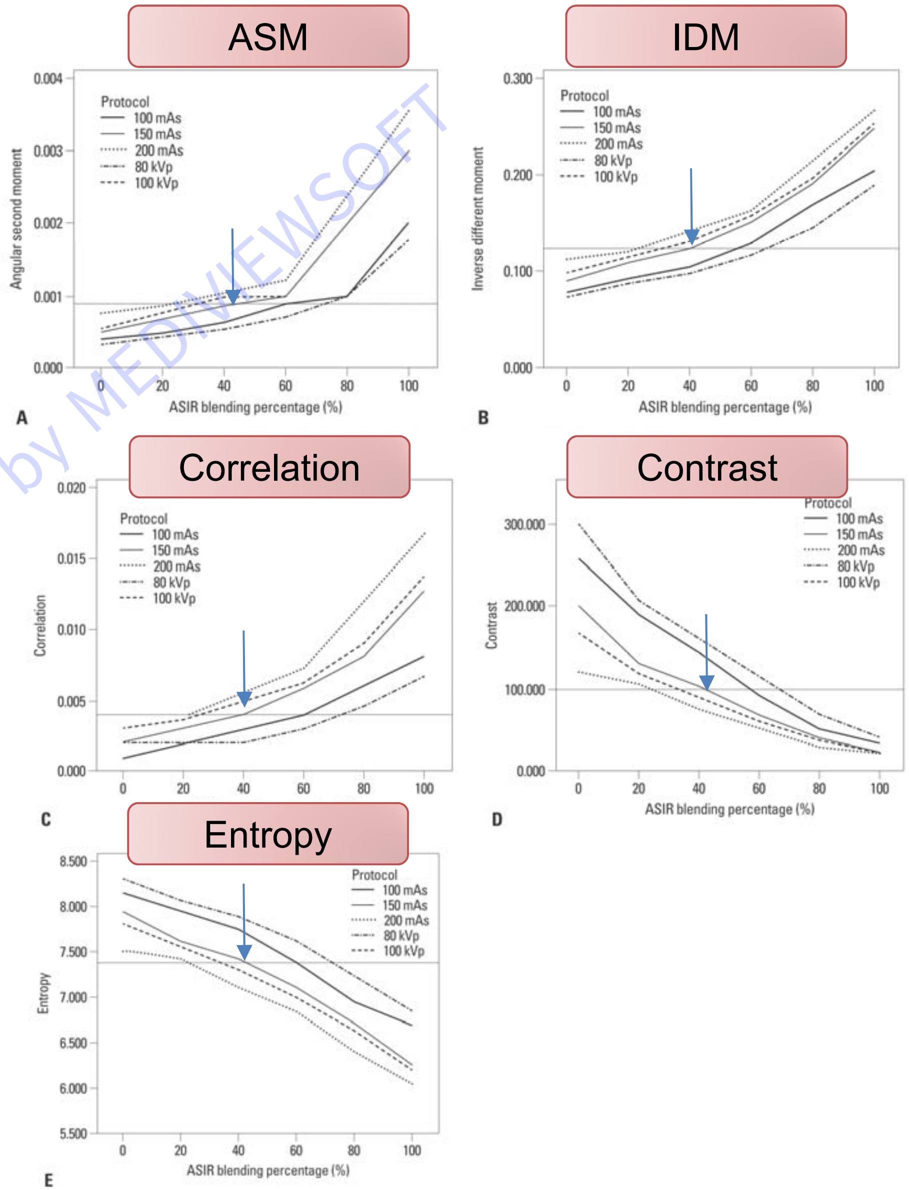


- After applying IR, general image noise decreases, but, there is also some artificial blotchy appearance of image.
- Moreover, this image appearance is usually pronounced at higher levels of IR algorithms, resulting in potentially precluding exploitation of the full potential of IR for reducing the radiation dose of CT examinations.

Texture analysis

- GLCM (grey-level co-occurrence matrices) method
  - Angular second momentum (**ASM**), Inverse difference moment (**IDM**): represent measures of homogeneity
  - **Correlation**: gray-tone linear dependencies within the image, high correlation value means a more consistent text value.
  - **Contrast**: the amount of local variation
  - **Entropy**: higher entropy values mean less homogeneous image

Images with 40% ASIR from 40% radiation reduction CT (from 250 mAs to 150 mAs) is similar image texture compared to full dose FBP image



Kim, H. G. Chung, Y.E. Yonsei Med J. 2015 Jan;56(1):253-61

Iterative Reconstruction

- Disadvantage of IR
  - Longer reconstruction times and higher computational power, especially the case for MBIR (10-90 min)
  - Blotch, pixelated appearance of images
  - Decreasing low contrast resolution in strong IR setting
    - Although IR techniques allow substantial noise reduction while maintaining high-contrast spatial resolution, low contrast resolution can be degraded by IR.

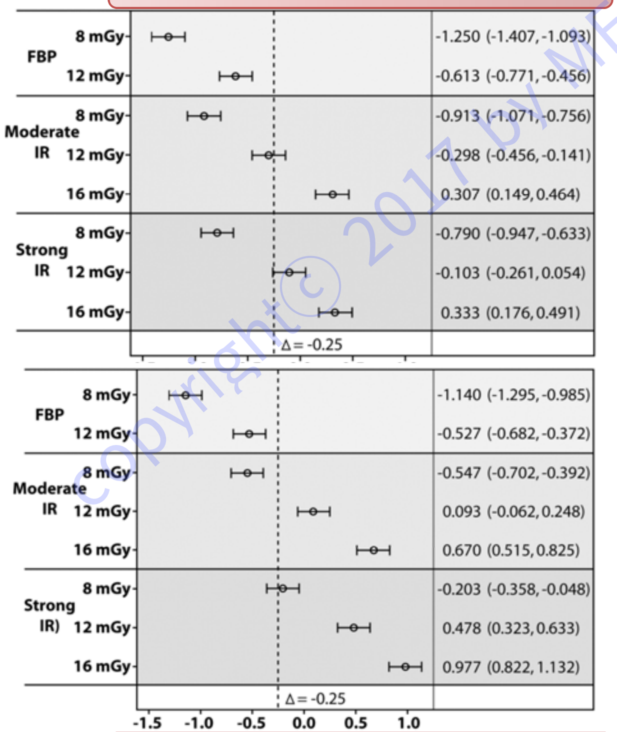
Morsbach, F.Invest Radiol. 2016 Aug 19.
Khawaja,Pediatr Radiol. 2015 Jul;45(7):1046-55

Disadvantage of IR-Low contrast resolution

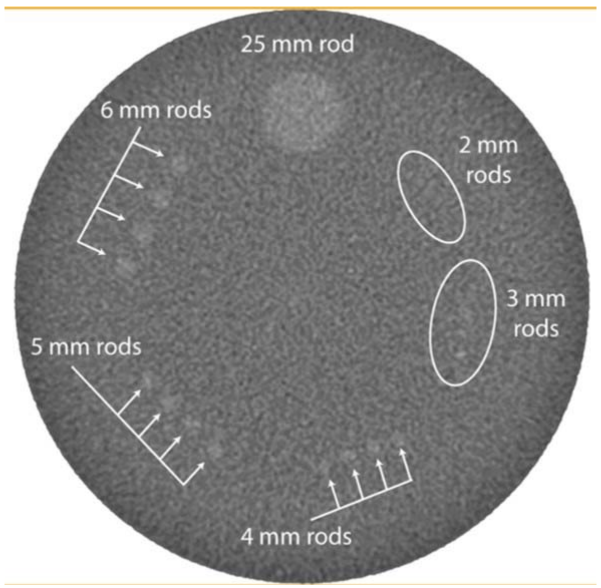
- Low contrast resolution performance by ACR
  - All four 6-mm rods were deemed to be visible by the physicist reviewer to pass the passing criteria.

Radiation dose reductions of 25%–50% with IR reduce the LCR relative to that achieved by using the full dose and FBP.

Lightspeed VCT w/ ASIR



Somatom Definitoin flash w/ SAFIRE



ACR CT Accreditation Program phantom

McCollough, C. H. Radiology. 2015 Aug;276(2):499-506

Iterative Reconstruction

- Disadvantage of IR
  - Longer reconstruction times and higher computational power,

Hence it is reasonable to apply medium degree of IR with less than 50% dose reduction for abdominal (liver) CT protocol.

  - Decreasing low contrast resolution in strong IR setting
    →IR algorithm can not preserve the low-contrast detectability in CT scan which is obtained below the certain level of radiation dose.

Morsbach, F.Invest Radiol. 2016 Aug 19.
Khawaja,Pediatr Radiol. 2015 Jul;45(7):1046-55

Iterative Reconstruction

Author	Year	Dose reduction	CTDIvol (mGy)	IR technique	Target Dz	
Kwon, H.J.	2015	35.37%	5.04	ASIR_V 30-50%	Abdomen	
Park, H.J.	2016	27%	8.8	IMR	HCC	
Shin, H.J.	2013	41.30%	18.9	SAFIRE 3-4	Abdomen	
Park, M.N.	2014	50%	5.63	SAFIRE 2	Liver metastasis	
Boning	2015	37.60%	6.34	ASIR 40%	Neuroendocrine tumor	
Song, J.S .	2015	47%	4.7	SAFIRE 2	Liver	
Pooler	2016	60-70%	5.04	ASIR 25-40%, MBIR	Liver low contrast lesion	Not appropriate
Vardhanabhuti	2014	85%	2	MBIR	Abdomen	Not appropriate
Khawaja	2015	85%	1.2	IMR	Liver	Not appropriate

DOUBLE DOSE REDUCTION

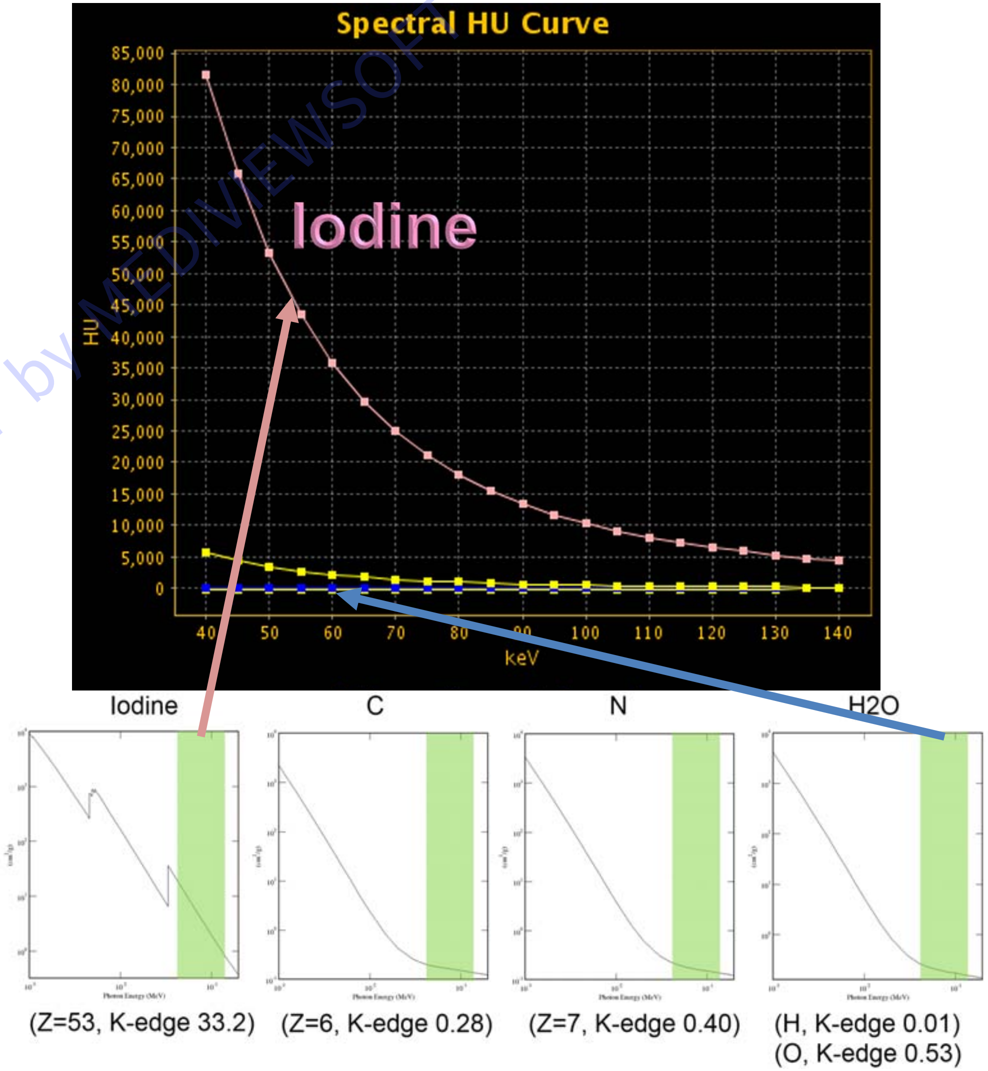
Double Dose reduction

- Double dose reduction
  - Reduce both radiation dose and CM dose by lowering tube voltage.

- Benefit of low kVp protocol
  - Radiation dose reduction
  - HU of iodine increases
    - As tube voltage decreases, it becomes closer to the k-edge of iodine and the photoelectric absorption of iodine increases, resulting in increased HU of iodine on CT

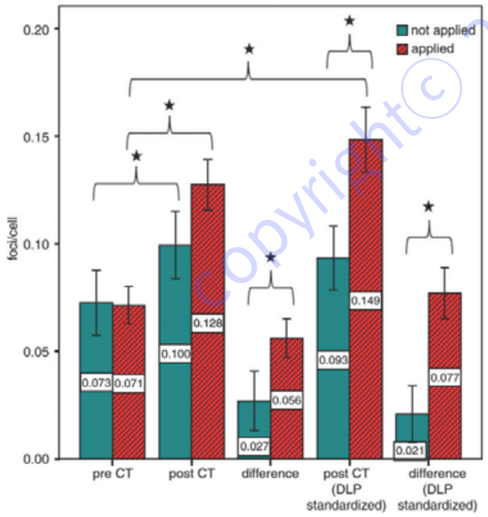
Double Dose reduction

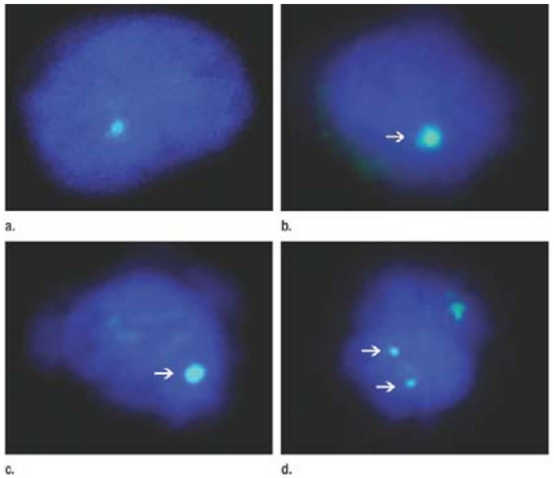
- Low kVp protocol
  - Iodine manifests with higher HU values than it does with the standard CT technique, even with the same CM dose.
  - ↑ conspicuity of hyper- and hypo-vascular structure or lesions



Drawbacks of contrast media

- Contrast induced nephropathy (CIN)
  - Increases short term in-hospital mortality/morbidity
  - Predisposing factor for long-term loss of kidney function
  - Incidence of CIN $\propto$ CM dose
- CM amplify DNA radiation damage during CT

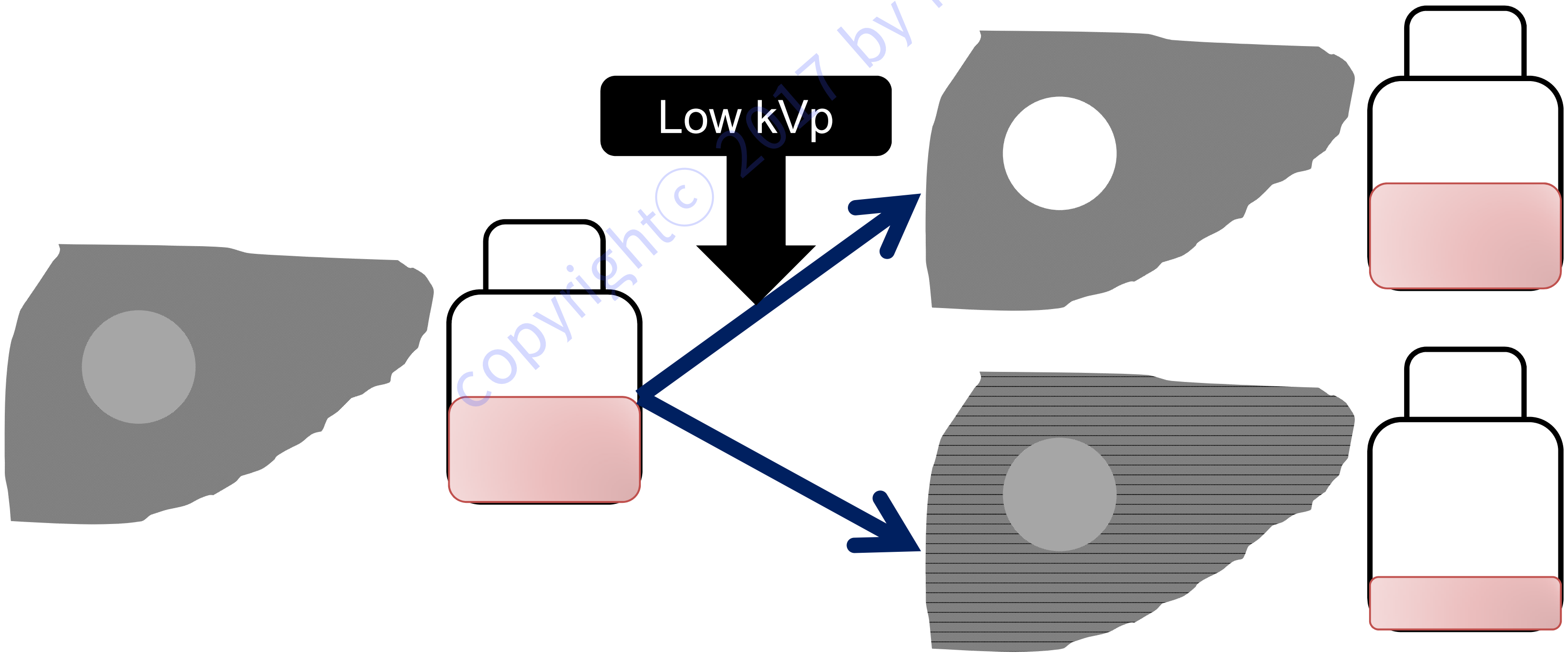


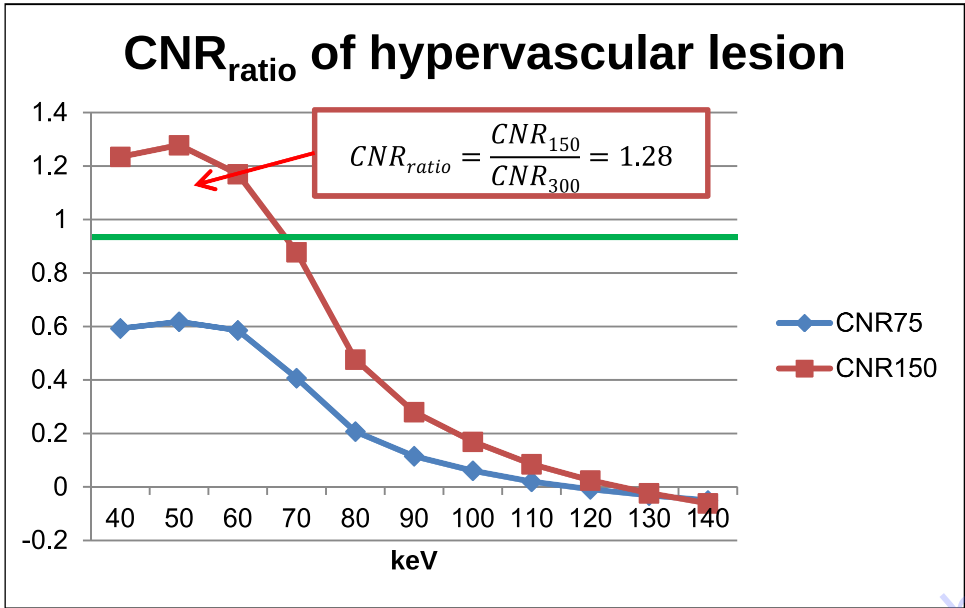


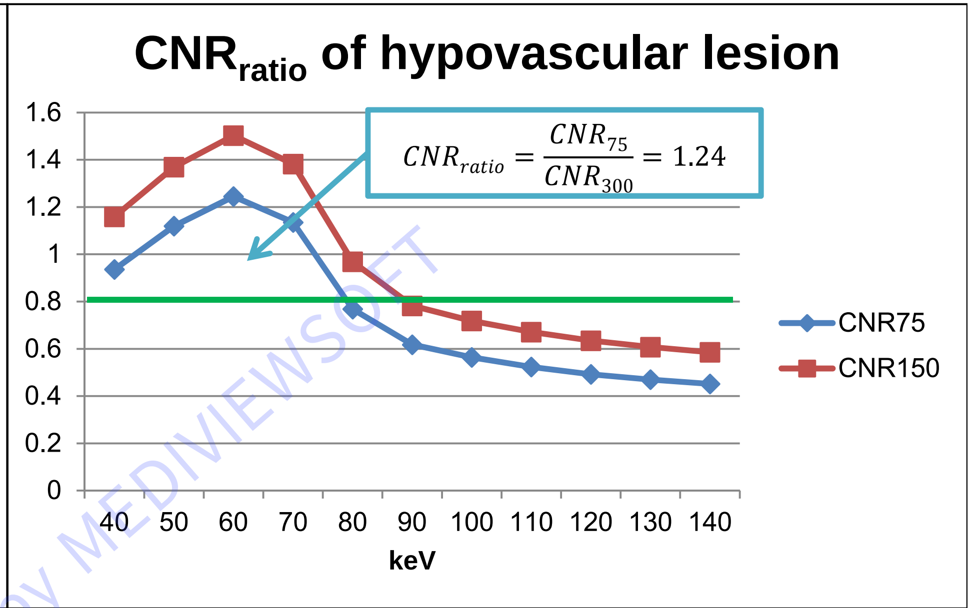
(Piechowiak, Peter et al. 2015)

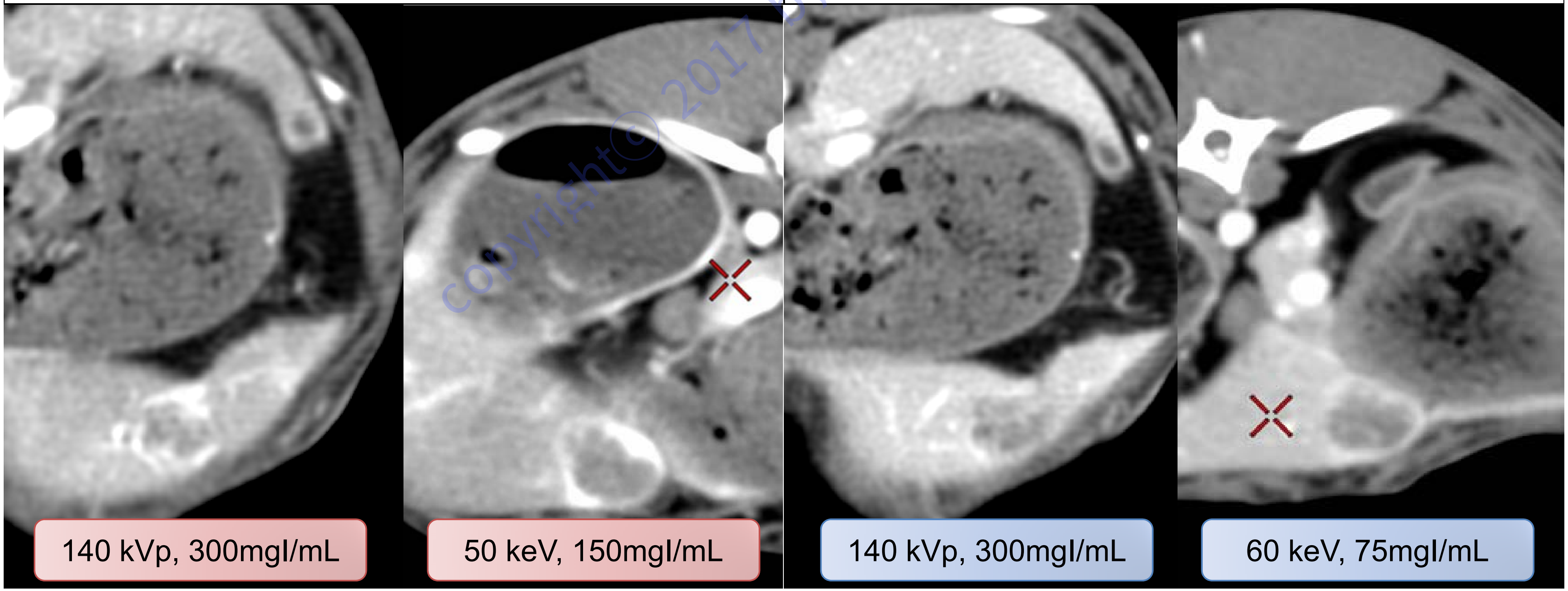
Double Dose reduction

- Increased HU of iodine in lower kVp protocol
  - ↑ conspicuity of hyper- and hypo-vascular structure or lesions
  - ↓ dose of CM with preservation of CNR of focal lesions




CNR$_{ratio}$ of hypervascular lesion
$CNR_{ratio} = \frac{CNR_{150}}{CNR_{300}} = 1.28$
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
40 50 60 70 80 90 100 110 120 130 140
keV
CNR75
CNR150


CNR$_{ratio}$ of hypovascular lesion
$CNR_{ratio} = \frac{CNR_{75}}{CNR_{300}} = 1.24$
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
40 50 60 70 80 90 100 110 120 130 140
keV
CNR75
CNR150

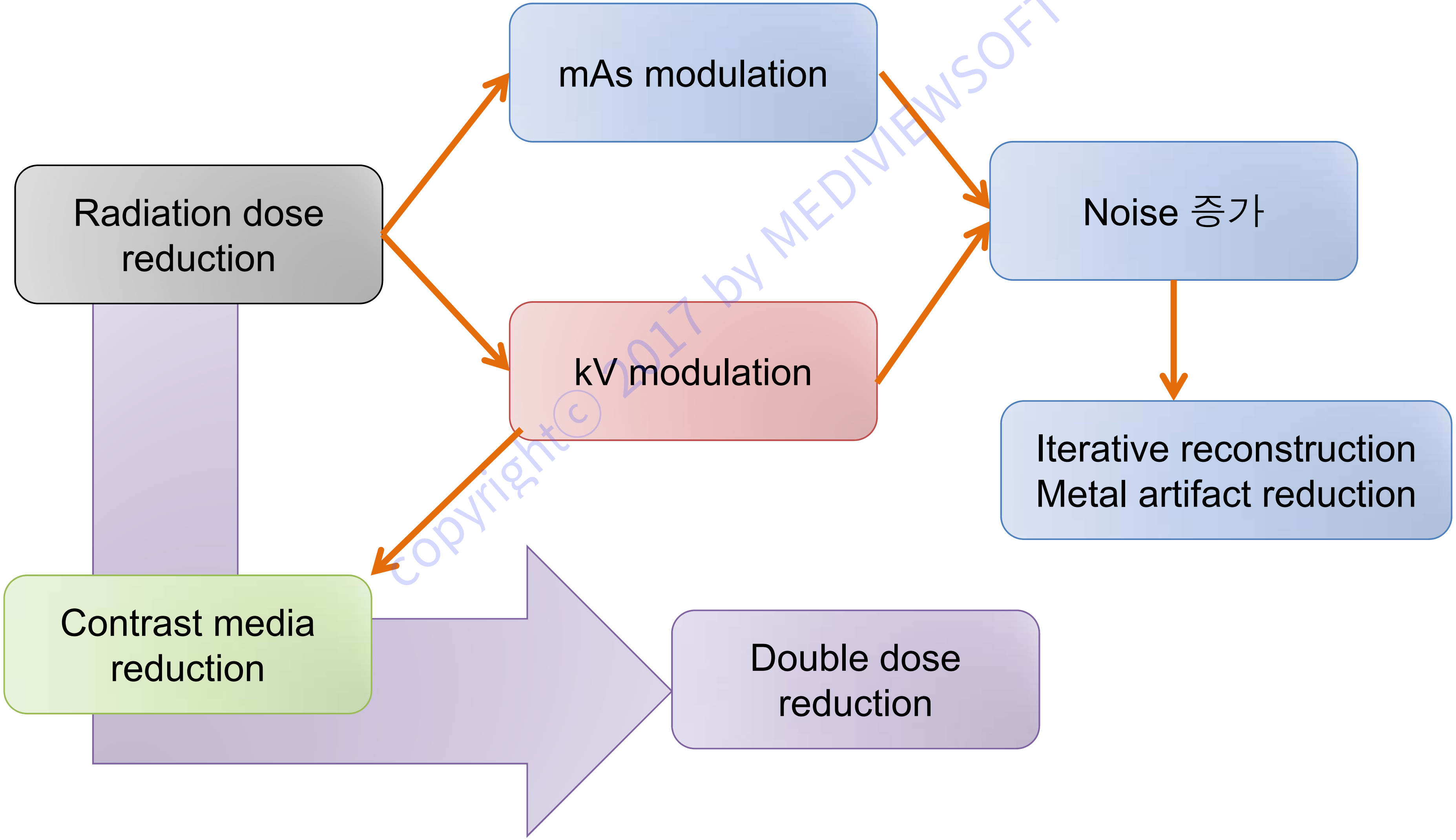

140 kVp, 300mgI/mL
50 keV, 150mgI/mL
140 kVp, 300mgI/mL
60 keV, 75mgI/mL

Double Dose reduction

Authors	CT machine	AEC	CM concentration (mg/mL)	CT protocol	Injection duration	RD reduction	CM Dose reduction	Body weight
Noda (2015)	GE (CT750 HE)	Yes, NI (12.0)	350	120 kVp, 600 mgI/kg vs 80 kVp, 500 mgI/kg vs 80 kVp, 400 mgI/kg	30 sec	33%	7.3%, 19.5%	
Takahashi (2014)	GE (64 MDCT)	YES	320,300, 370	120 kVp, 600 mgI/kg, NI=11.0 vs 100kVp, 480 mgI/kg with ASIR 40%, NI=14	30 sec	37%	20%	BW <70 kg
Namimoto (2012)	Philips (Brillance 64)	Only at 120 kVp	300, 370	120 kVp, 600 mgI/kg, 243-450 mAs vs 80kVp, 386 mAs 450 mgI/kg with IDOSE 60%/ 40% blend of IR/FBP	30 sec	28.%	25%	
Nakaura (2012)	Philips (Brillance iCT)	Yes	300, 350, 370	120 kVp, 600 mgI/kg, ref CTDIvol 20mGy vs 80kVp, ref CTDIvol 12mGy 450 mgI/kg with IDOSE 40%	30 sec	48-51%	40%	
Yanaga (2011)	Philips (Brillance 64)	Only at 120 kVp	370	120 kVp, 600 mgI/kg, 300 mAs, ref CTDIvol 20mGy vs 80kVp, 600 mAs, 444 mgI/kg with IDOSE 40%	30 vs 15 sec	13%	26%	BW <70 kg

Shen, Y Int J Clin Pract. 2016 Sep;70 Suppl 9B:B5-B15.

Summary



mAs modulation
Radiation dose reduction
Noise 증가
kV modulation
Iterative reconstruction
Metal artifact reduction
Contrast media reduction
Double dose reduction