Absorbed dose analysis of dental cone-beam computed tomography using Monte Carlo simulations

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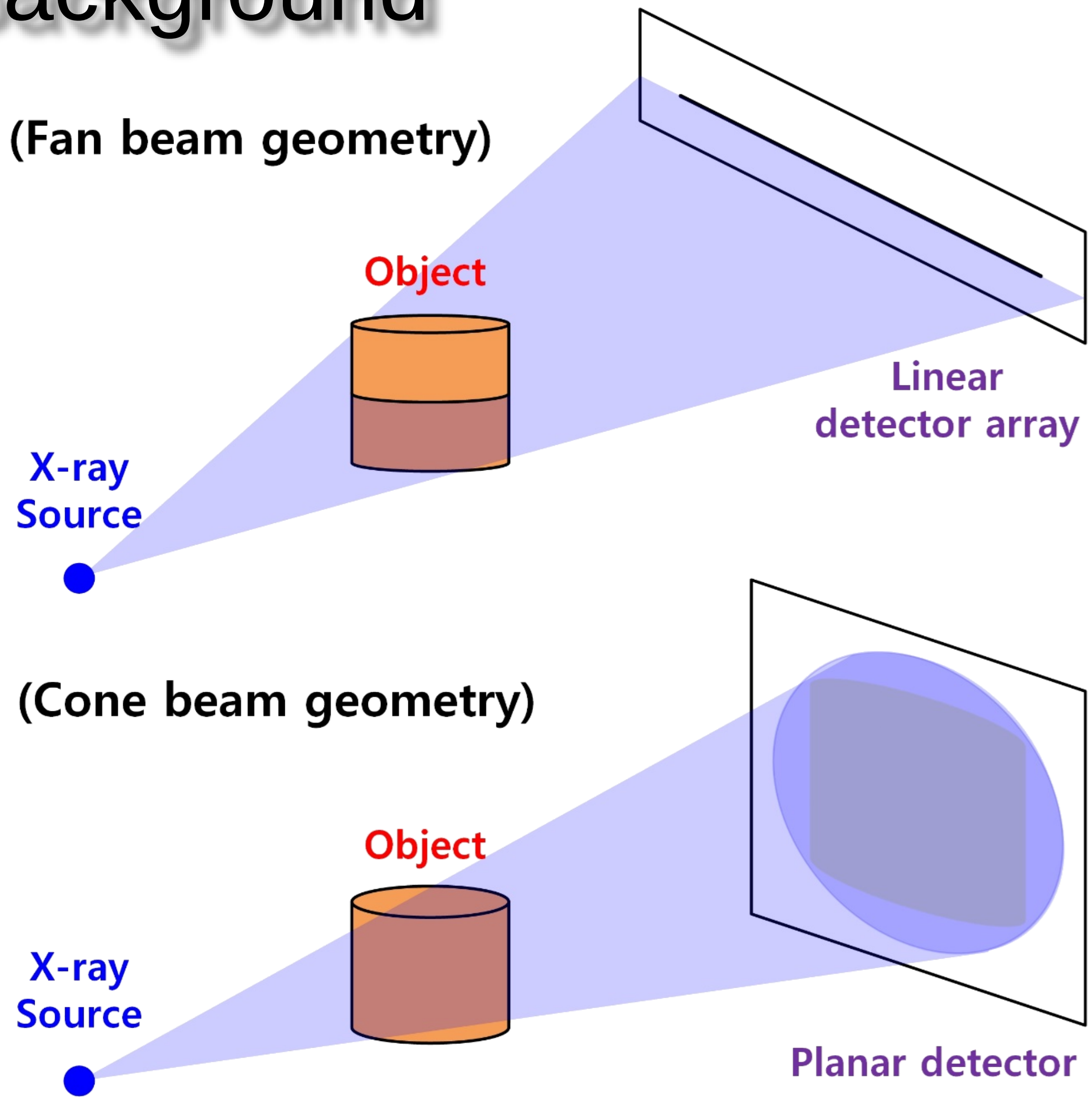
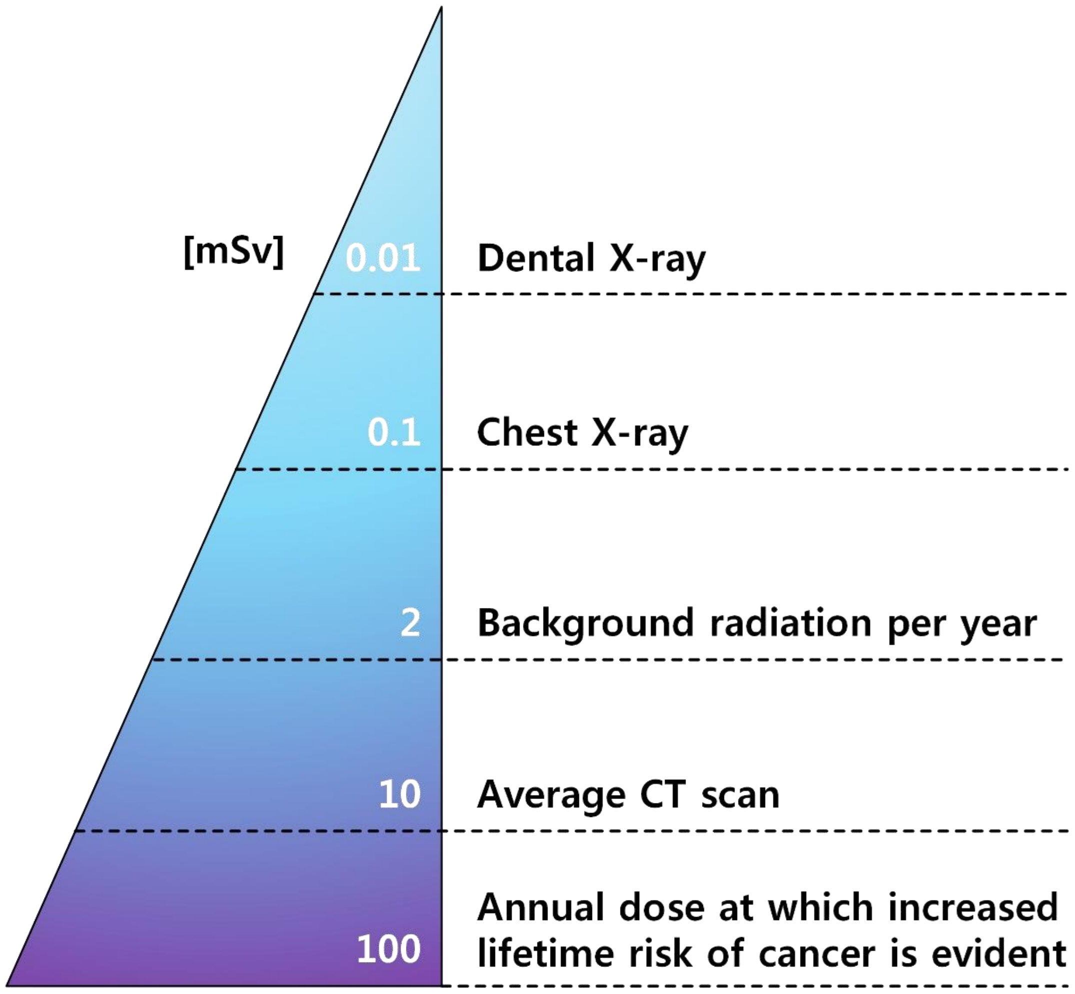
Background





sources: BBC, Guardian Datablog, Mayo Clinic, XKCD

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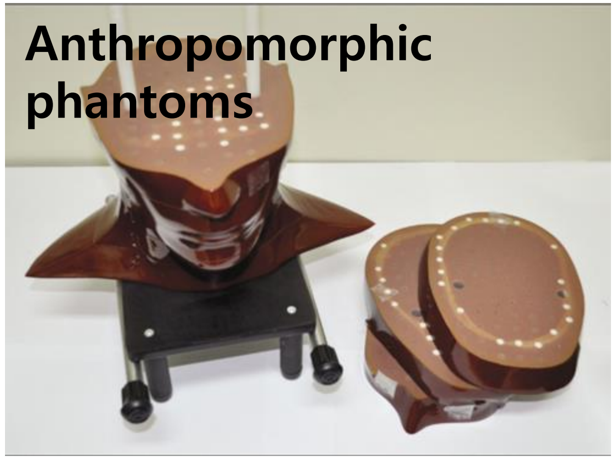
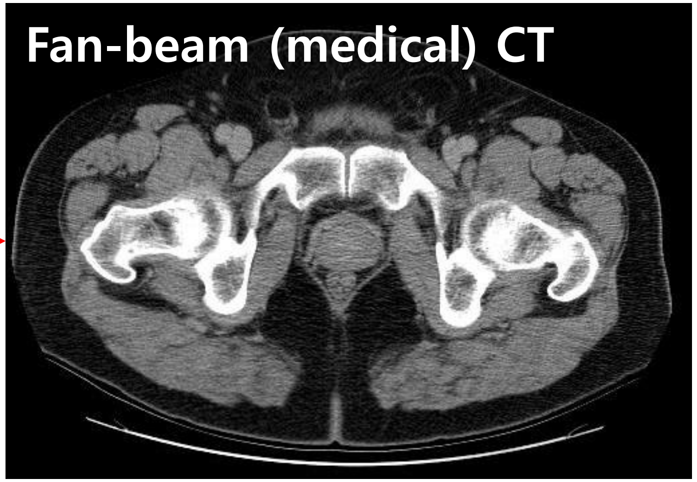
Background

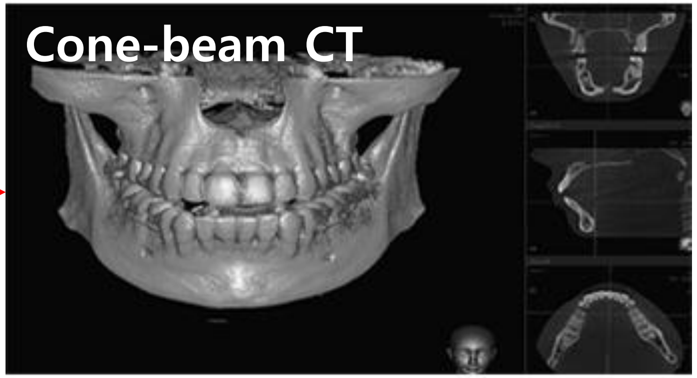
- Patient dose "estimation" methods



Boltzmann transport equation

$$\frac{\partial f}{\partial t} + \dot{\vec{v}}\nabla_v f + \dot{\vec{r}}\nabla_r f = \left(\frac{\partial f}{\partial t}\right)_{\mathrm{coll}}$$





Objectives

- To investigate 3-D patient dose distributions for typical dentoalveolar CBCT scanning protocols by using the Monte Carlo method
  - Organ-wise dose distributions
  - Interaction-wise dose distributions

- To investigate the effective doses in width-truncated cone-beam geometries

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Dental CBCT simulations

- MC simulations were performed by using

MCNP5™ Los Alamos NATIONAL LABORATORY

- Particle tracking (PTRAC)
- Organ-wise dose analysis
- Interaction-wise dose analysis
- Anthropomorphic phantom (XCAT)

- ICRP-103 tissue weighting factors

Organ	Weighting factor
Red bone marrow	0.12
Oesophagus	0.04
Thyroid	0.04
Skin	0.01
Bone surface	0.01
Brain	0.01
Salivary glands	0.01
Remainder	0.12

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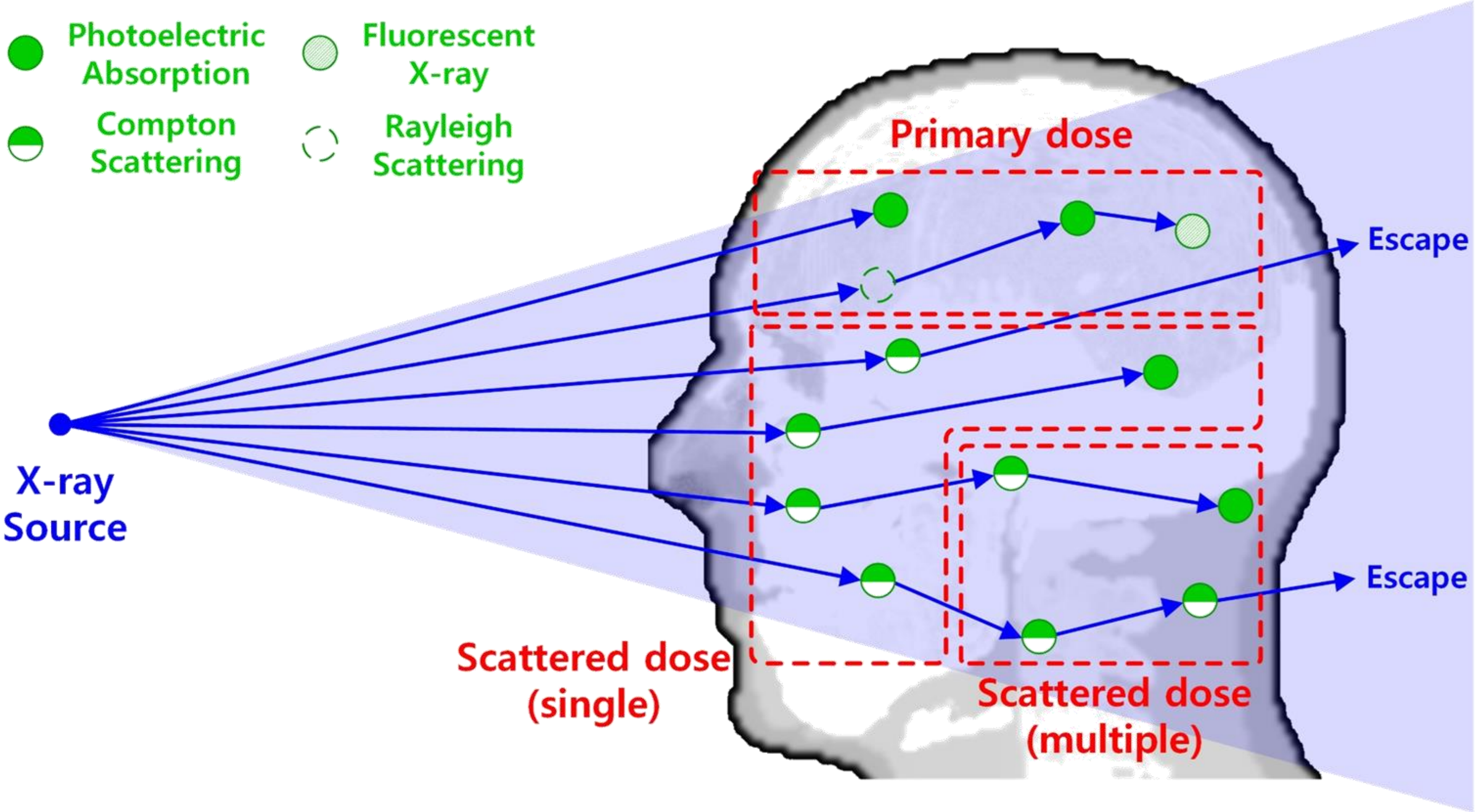
Dental CBCT simulations



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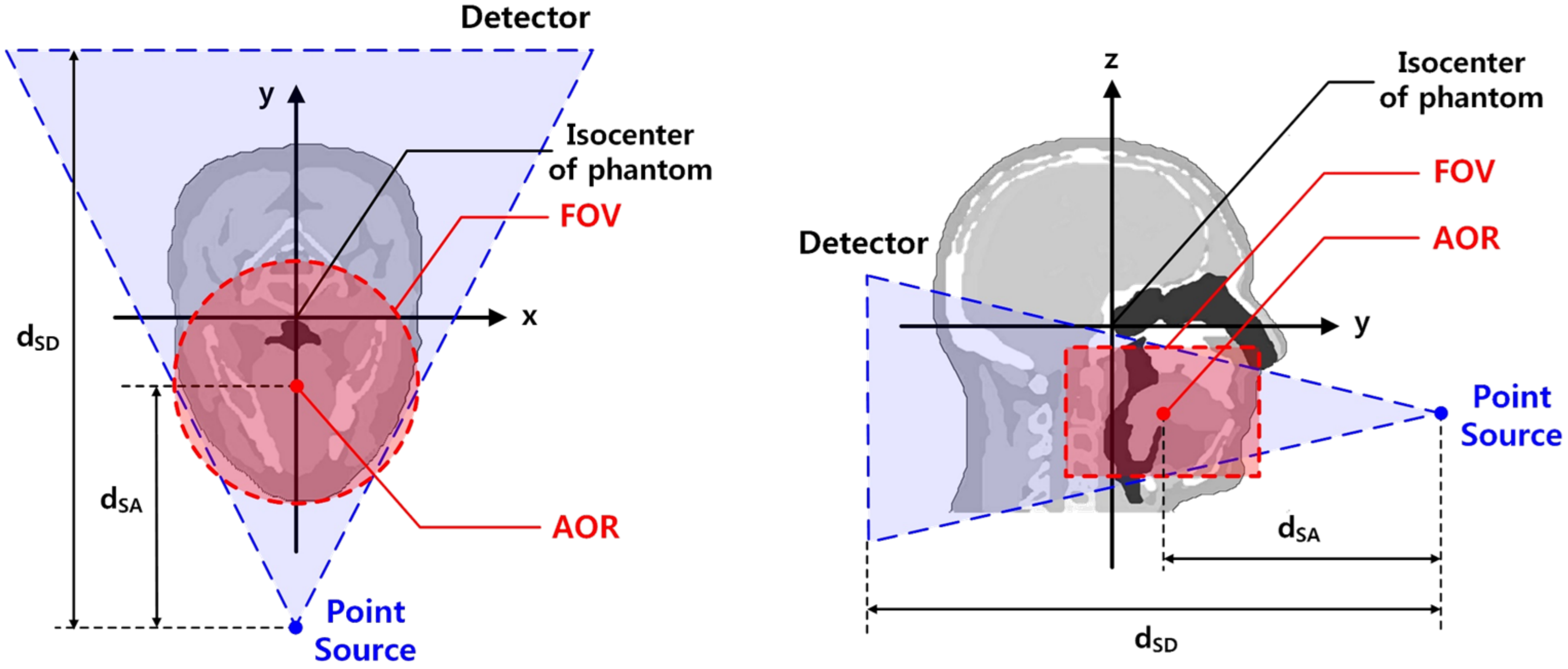
Dental CBCT simulations

- Scanning protocols



FOV	Tube voltage	Tube current	Magnification
130×80 mm	90, 100, 120 kVp	20 mAs	1.4

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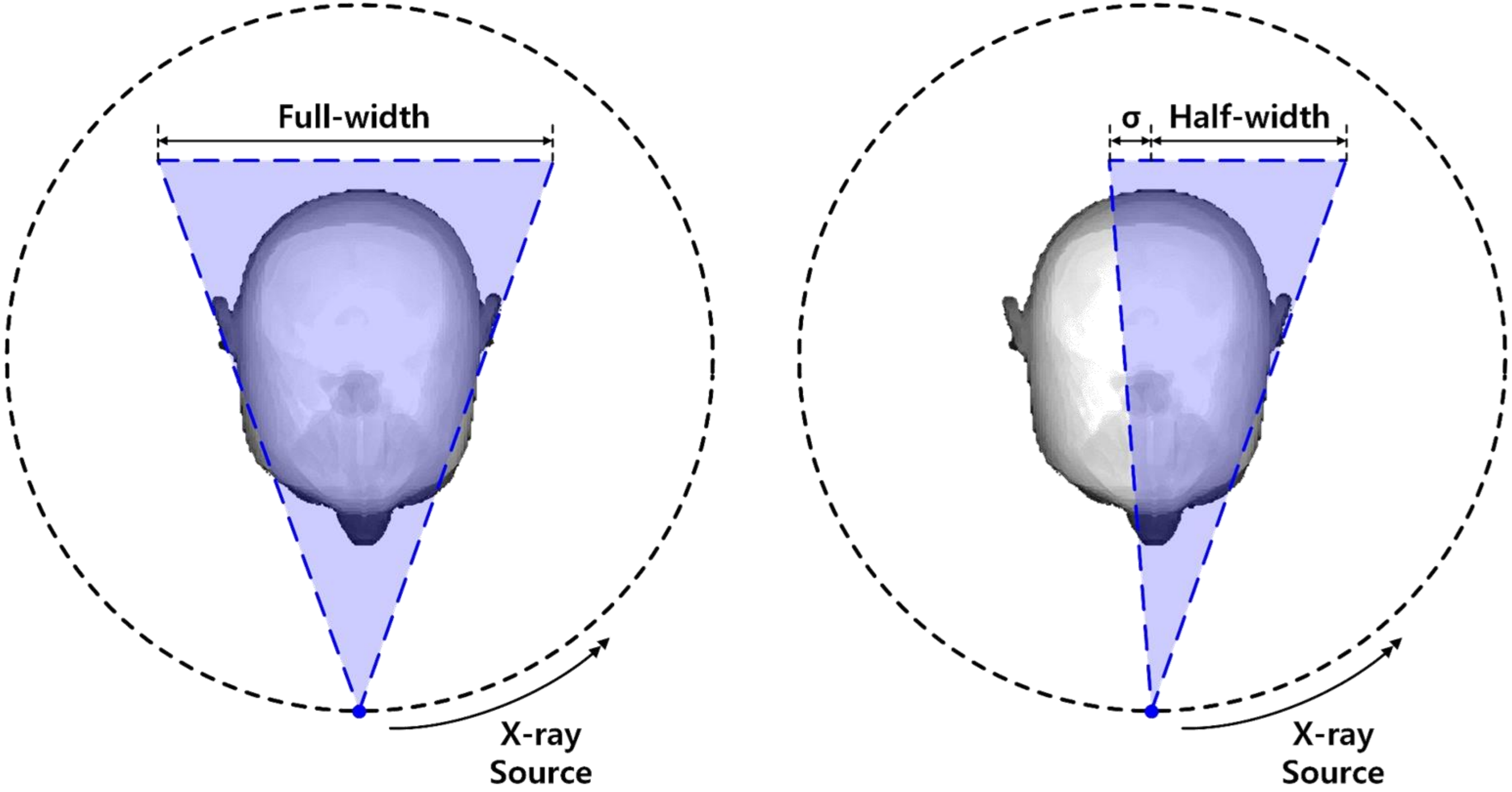
Dental CBCT simulations

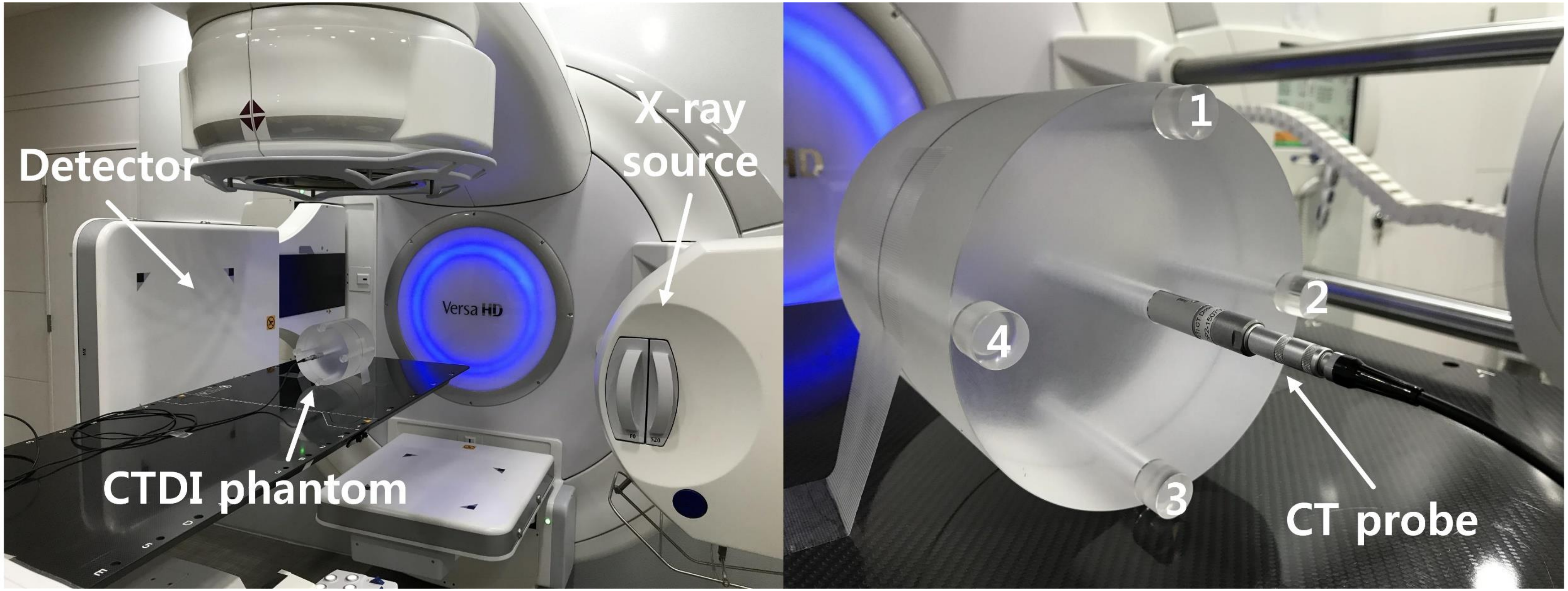
- Width-truncated CBCT



FOV	Tube voltage	Tube current	Overscan width
130×80 mm	100 kVp	20 mAs	5, 10, 20%

Validation

- Experimental measurements



Tube voltage	Tube current	Scan angle
70, 100, 120 kVp	18.3 mAs	200^{o}

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Results

- CTDI dosimetry

Tube voltage (kVp)	70					100					120				
Position	C	1	2	3	4	C	1	2	3	4	C	1	2	3	4
Measurement (mGy)	.111	.078	.189	.217	.116	.391	.253	.647	.711	.379	.712	.457	1.09	1.21	.666
Monte Carlo (mGy)	.123	.084	.206	.239	.121	.436	.283	.679	.772	.406	.775	.477	1.12	1.27	.654
Difference (%)	10.8	7.6	8.5	10.0	4.1	11.6	11.9	4.8	8.6	7.1	8.9	4.4	3.3	5.5	1.8

Max. diff.

(7% on average)

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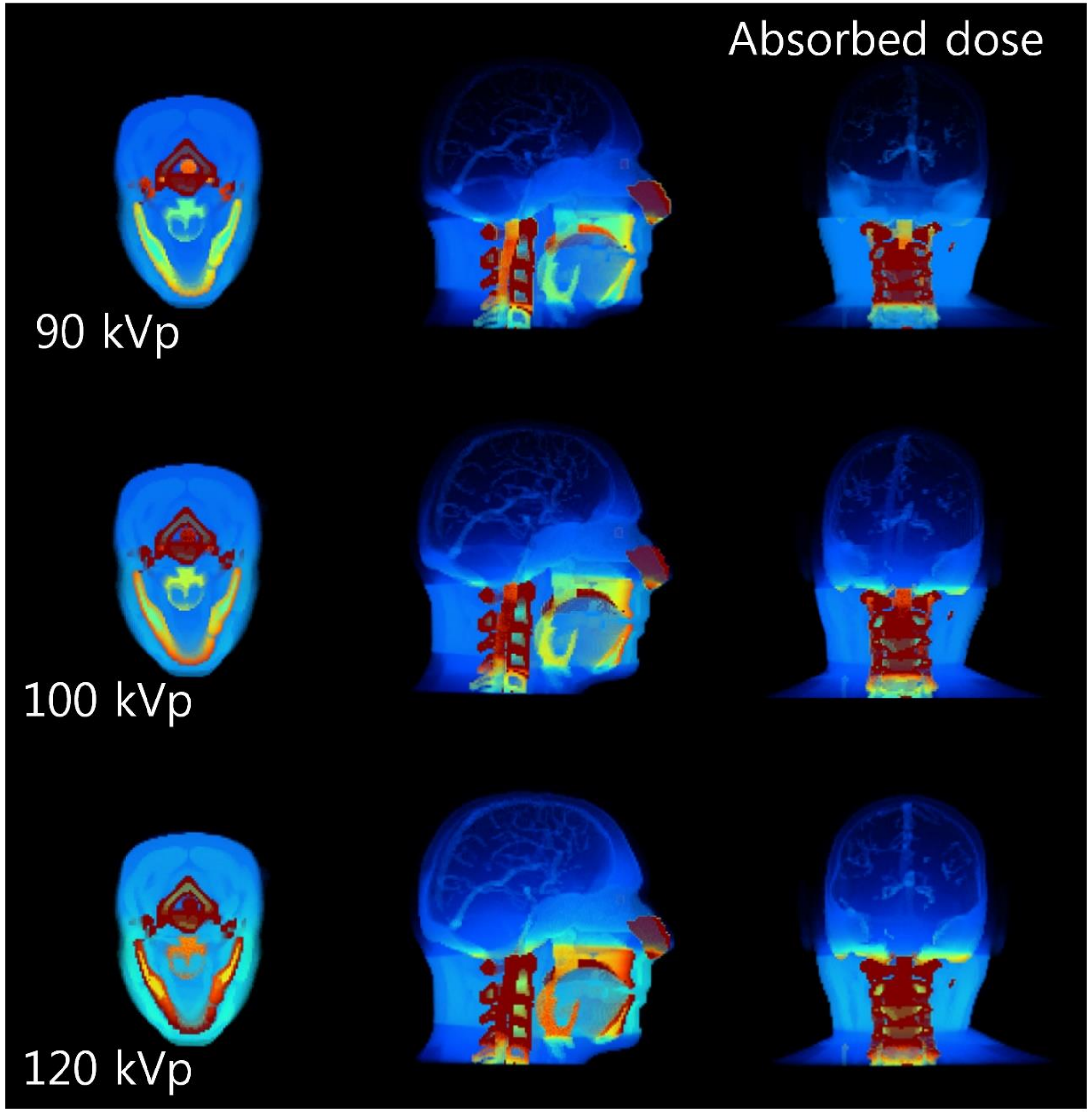
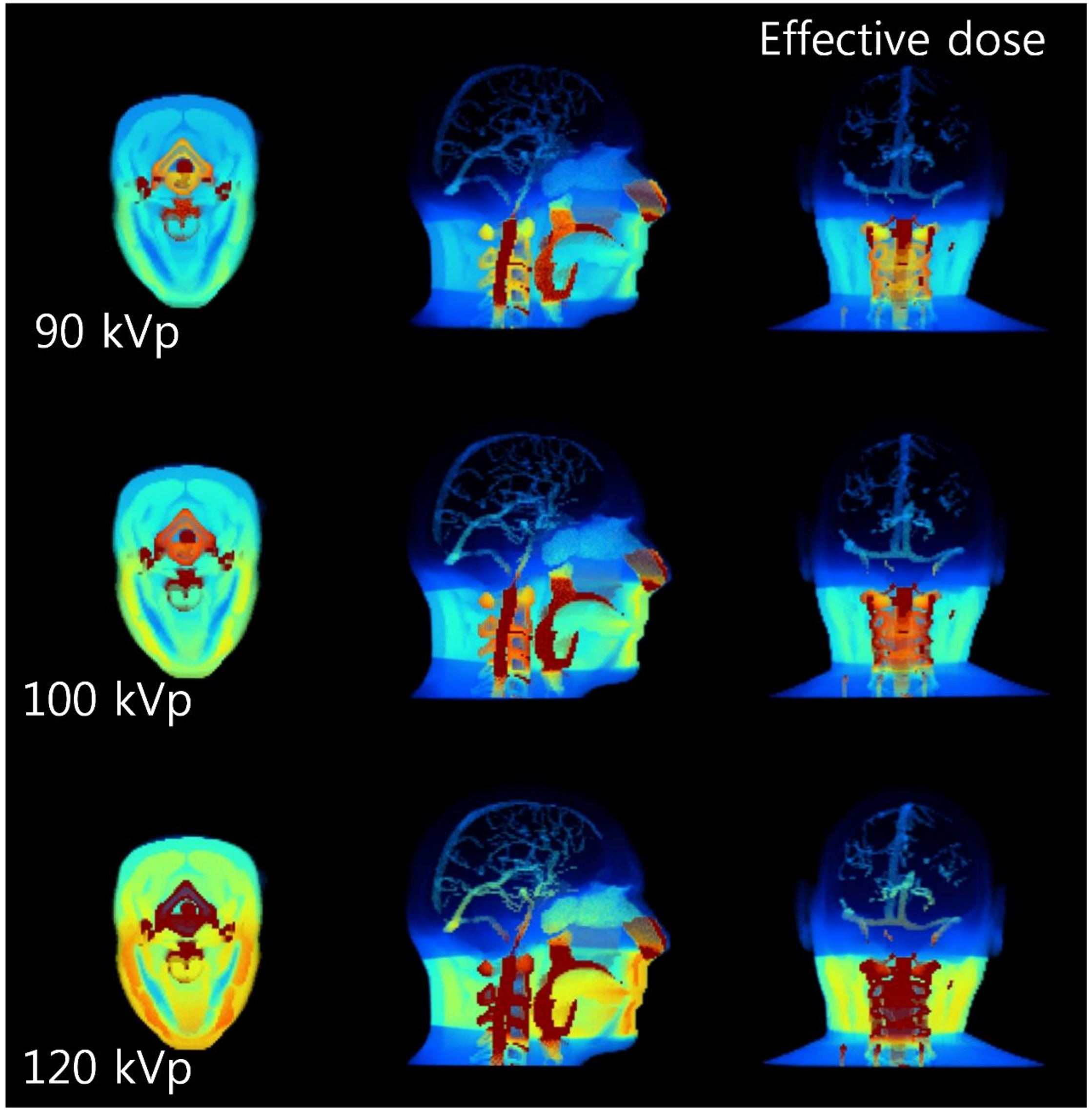
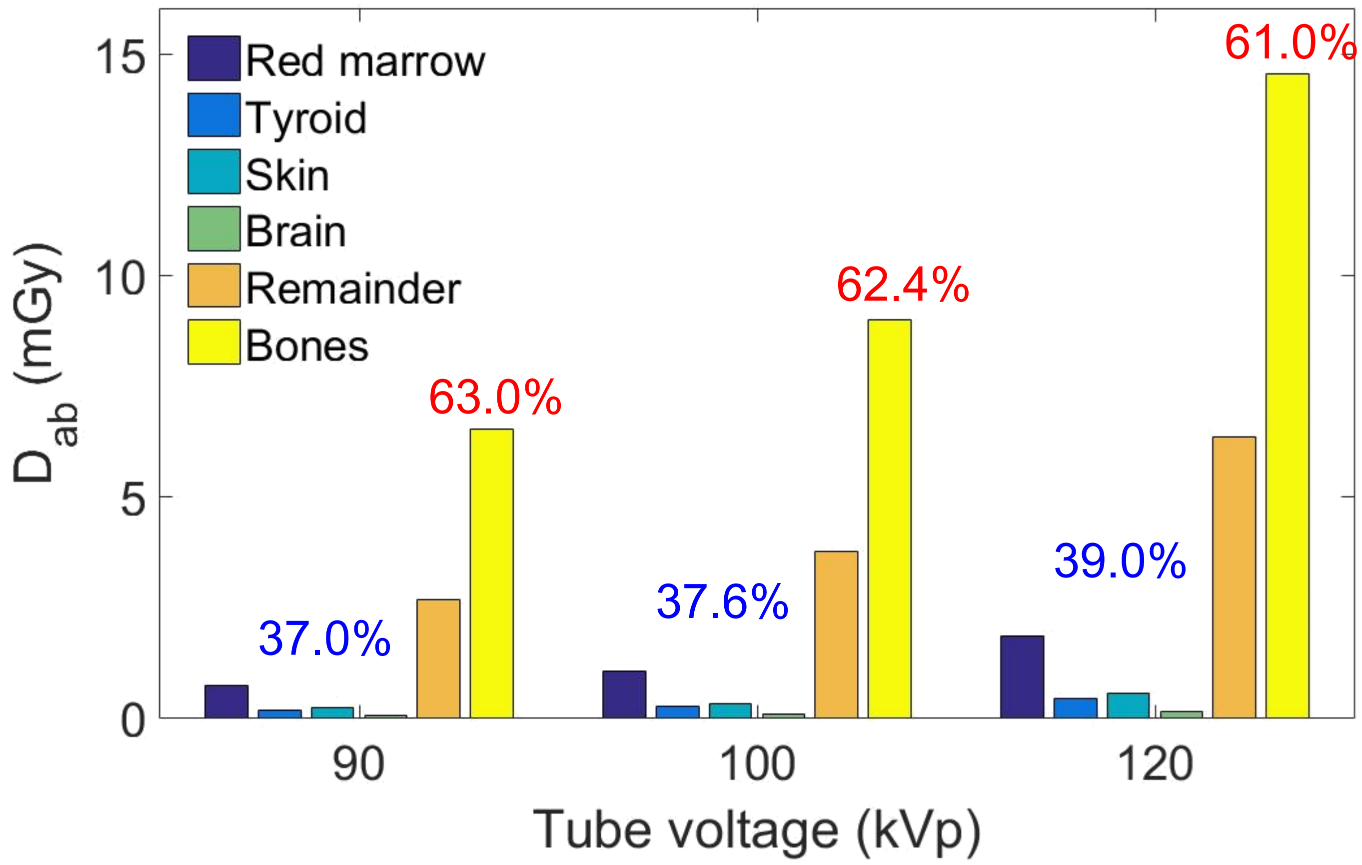
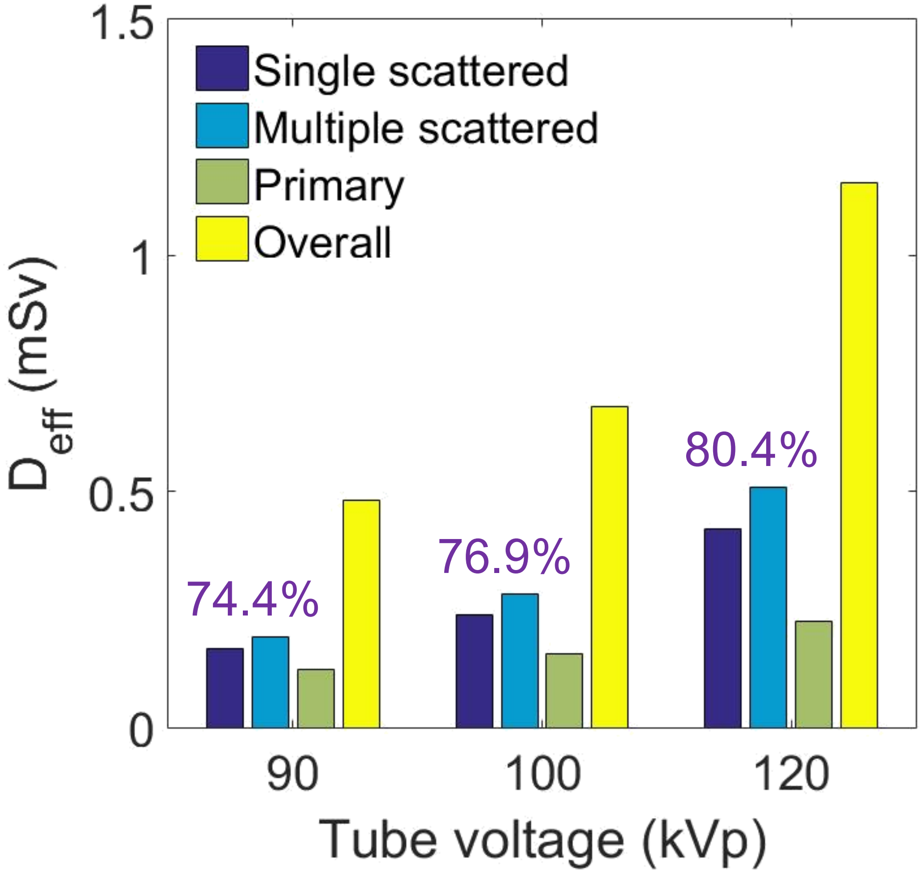
Dose-maps (full-width geometry)





Organ / Interaction-wise dose analysis





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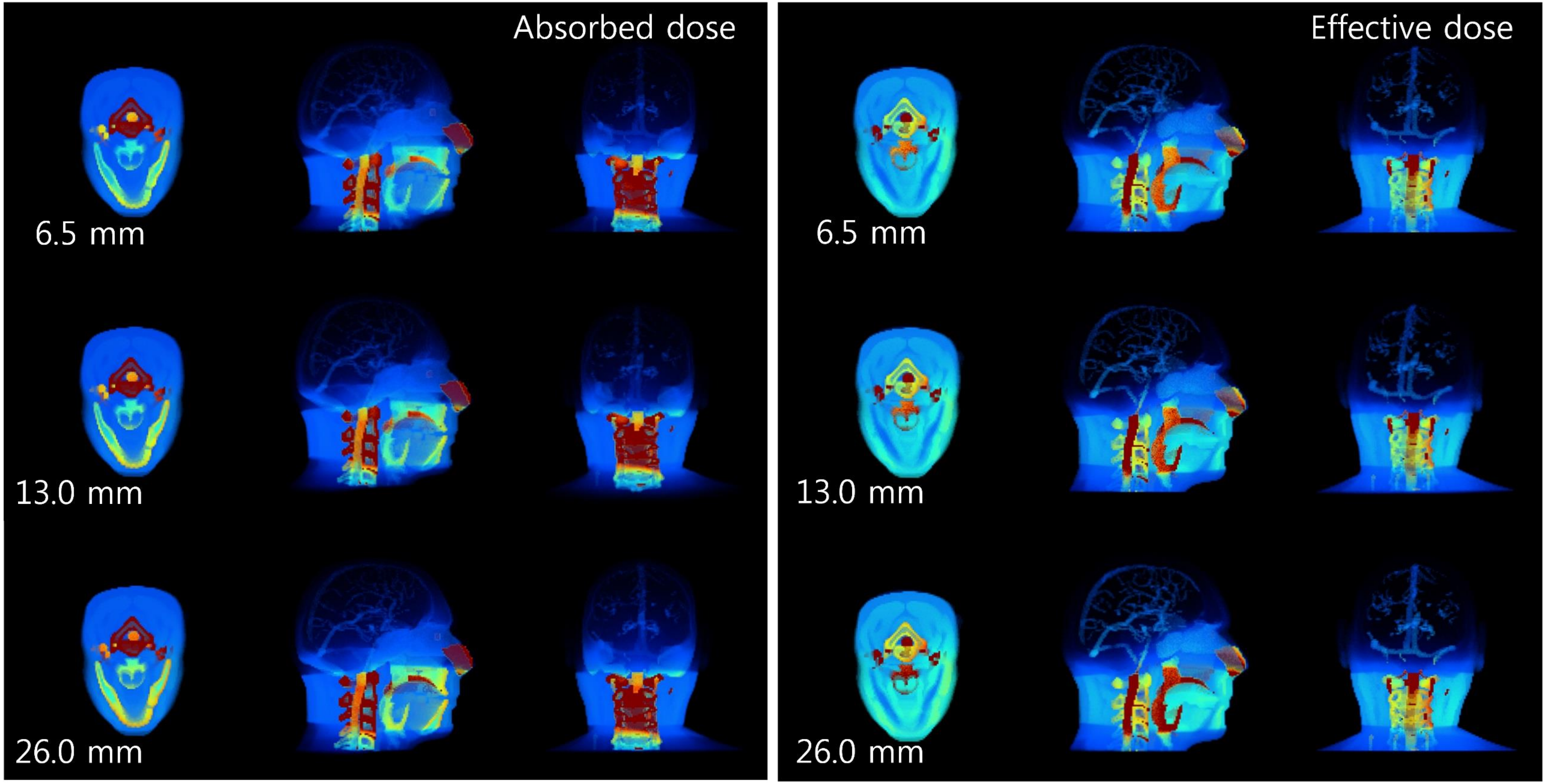
Dose-maps (width-truncated geometry)



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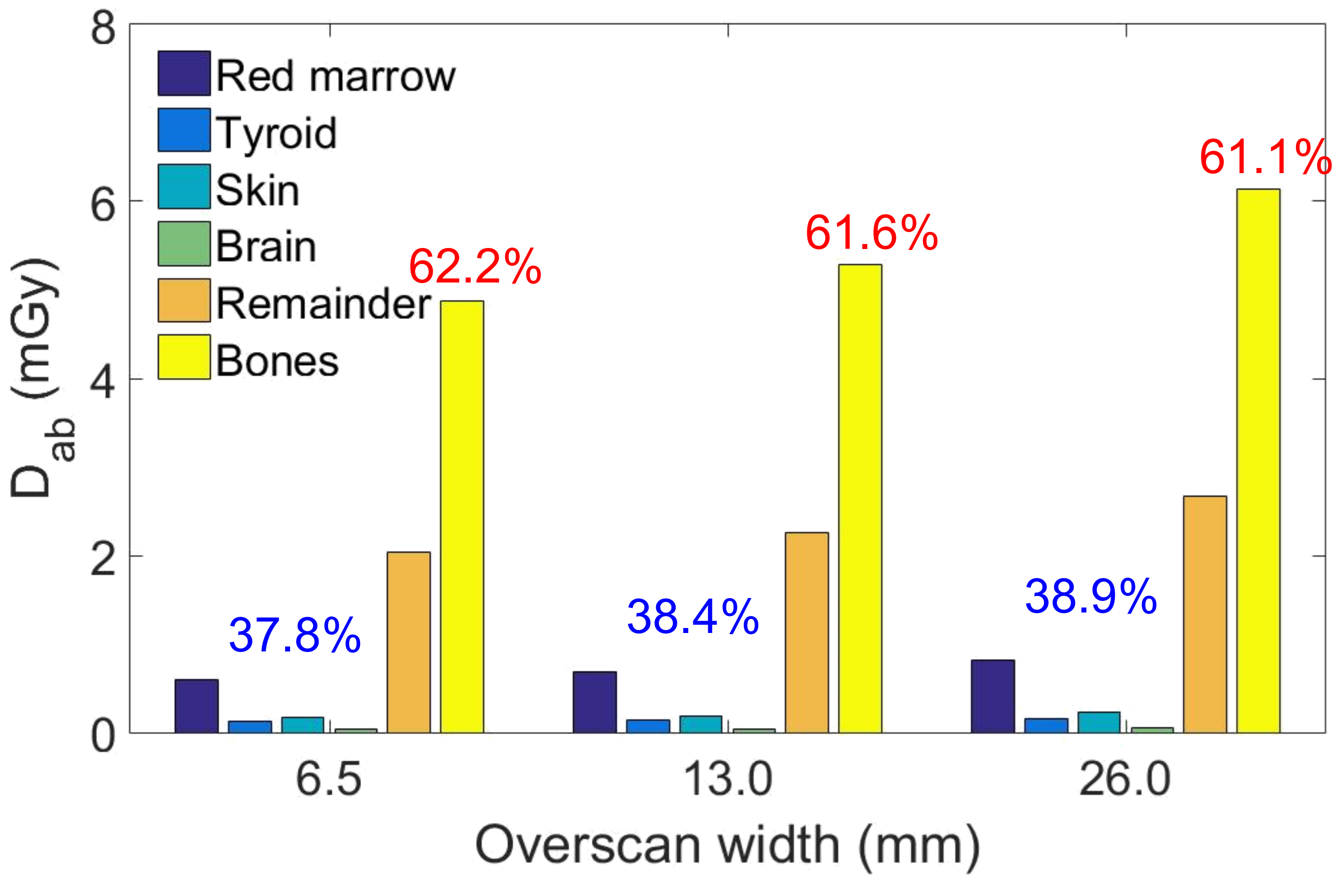
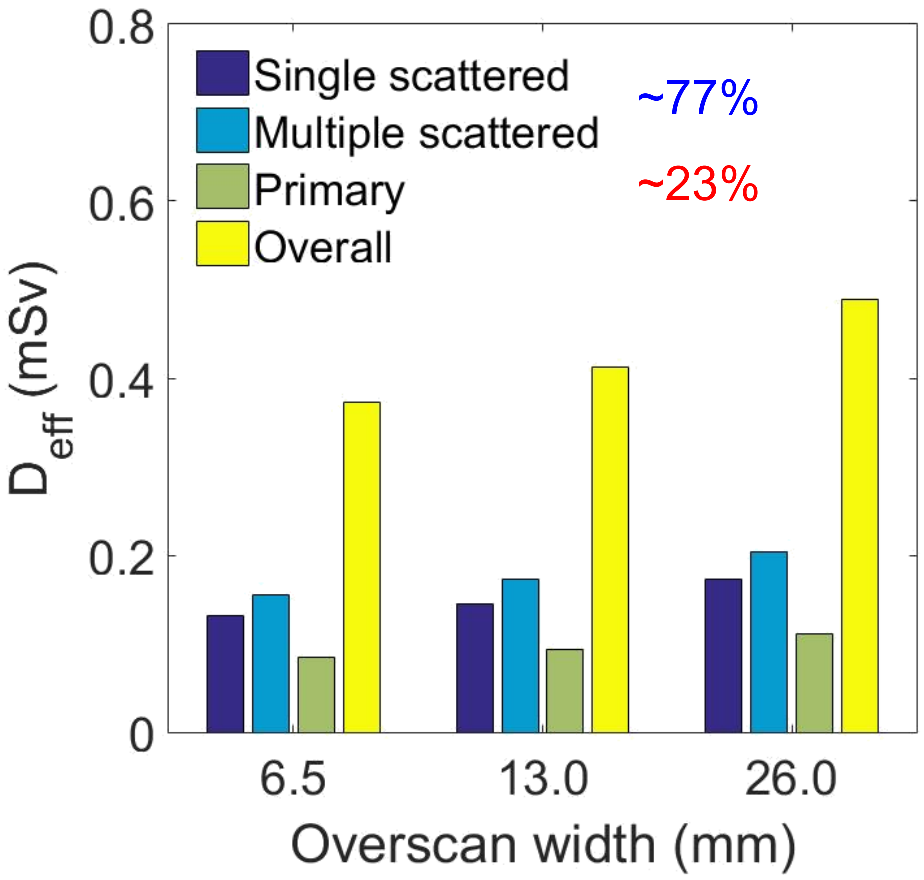
Organ / Interaction-wise dose analysis





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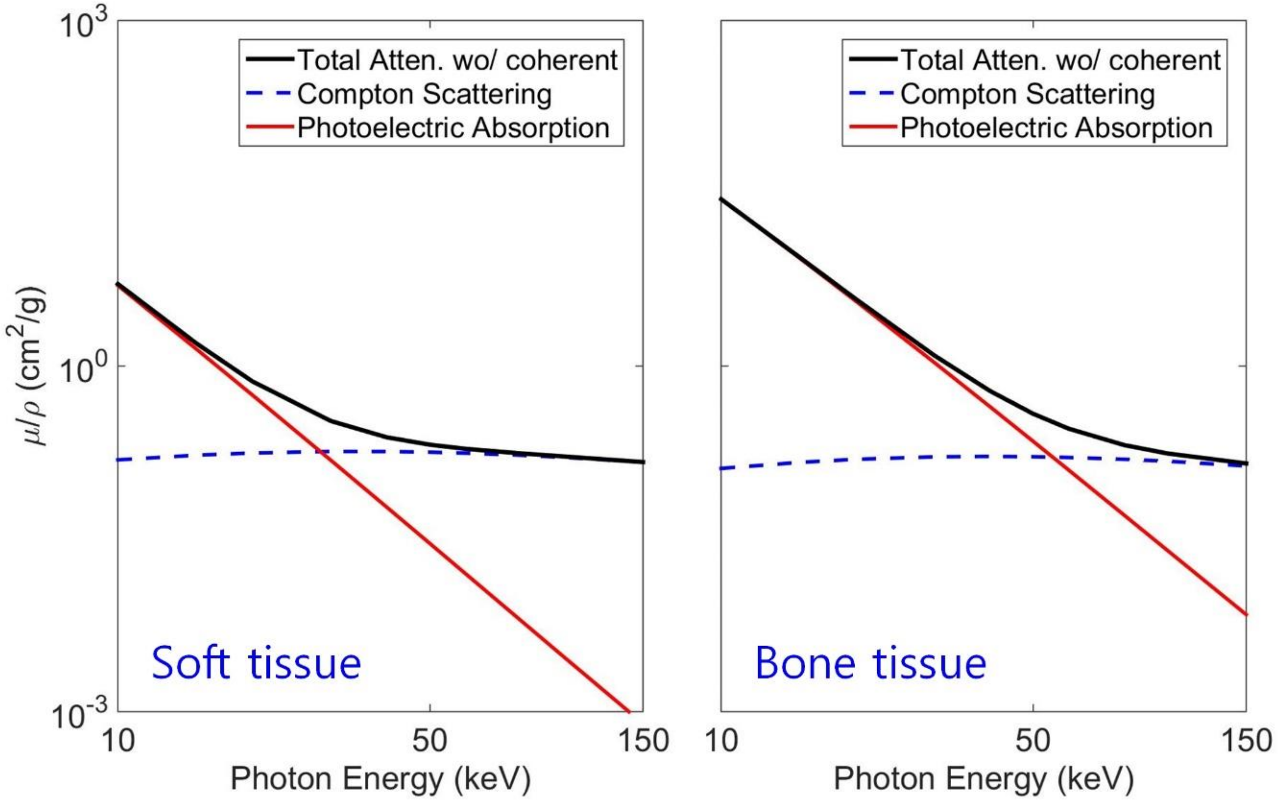
Discussion

1. The difference between measurement and simulation was 7% on average

2. With increasing tube voltages,

kVp	90	120
D_{ab} (mGy)	6.51 (100%)	14.55 (220%)
D_{eff} (mSv)	0.48 (100%)	1.15 (240%)



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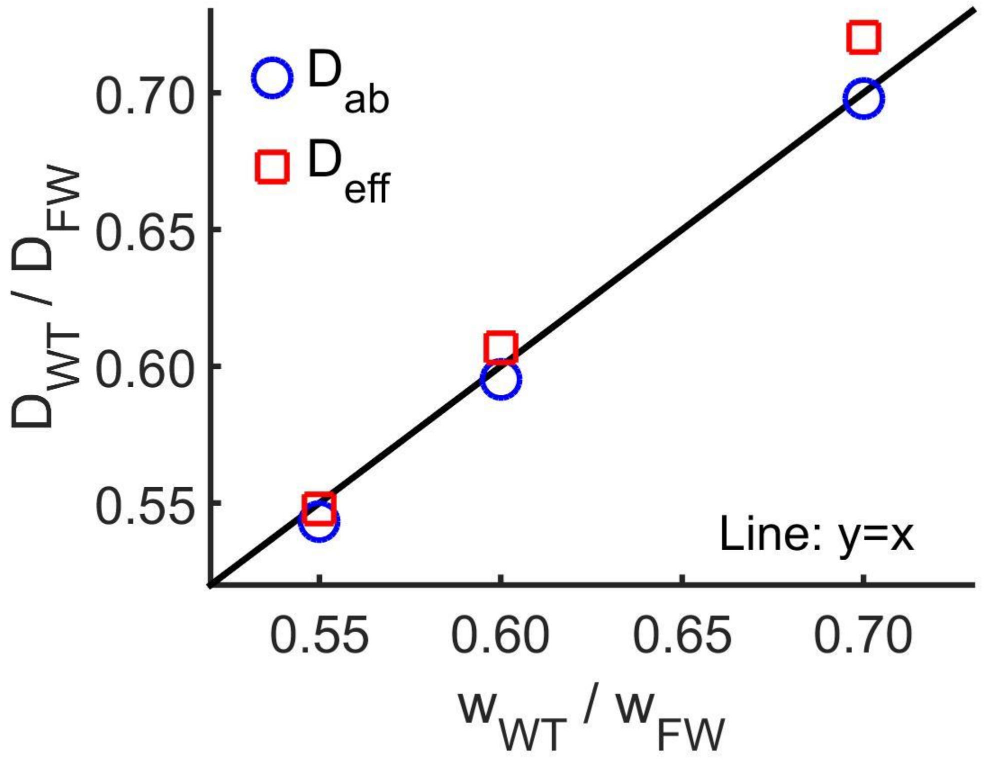
Discussion

3. In the width-truncated geometry,



4. The scattered dose had a greater effect on the human body than the primary dose

- However, very few doses were absorbed to the brain and eye lens (only scattered photons could be reached)
- In fact, more than 80% of the absorbed dose were concentrated in the x-ray irradiation field

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Conclusion

- The effective dose can be increased significantly even with relatively small increases in tube voltage or overscan width
- There are not many scattered photons that transmit far away from the region directly exposed by the x-rays, even if there are many scatter events
- In order to reduce patient dose in dental CBCT, it is important to ensure that excessive tube voltage or overscan width is not applied and proper FOV positioning
- Finding the optimal scan protocols which reduce the patient dose while maintaining the quality of the reconstructed images will be our next study.

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Thanks for attention.

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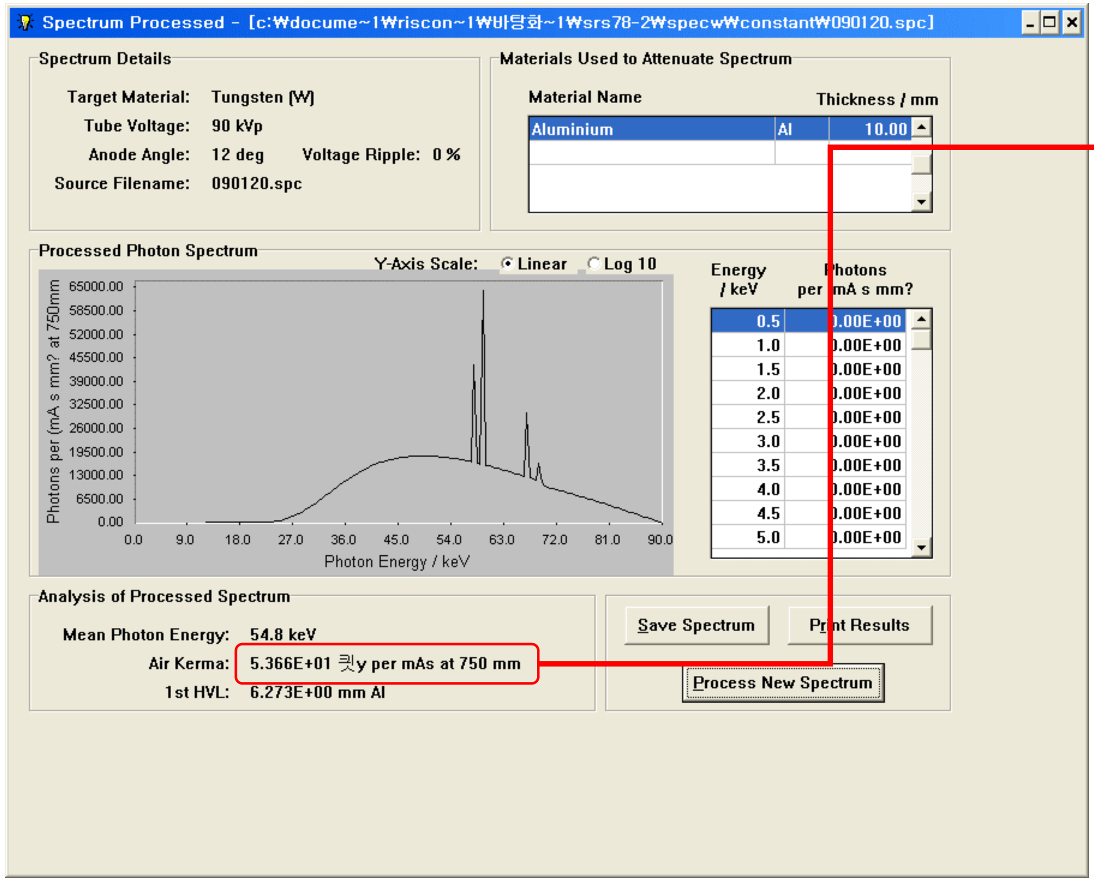
Validation

- Monte Carlo normalization factor



$$\left(D_{\text{air,measured}}\right)_E = \left[{}^{\mu\text{Gy}}/_{\text{mAs}}\right]$$

$$\left(D_{\text{air,simulated}}\right)_E = \left[{}^{\mu\text{Gy}}/_{\text{particle}}\right]$$

$$(\text{NF})_E = \frac{\left(D_{\text{air,measured}}\right)_E}{\left(D_{\text{air,simulated}}\right)_E} = \left[{}^{\text{particle}}/_{\text{mAs}}\right]$$

$$\left(D_{\text{absolute}}\right)_E = \left(D_{\text{simulated}}\right)_E \times (\text{NF})_E \times \text{total mAs} = [\mu\text{Gy}]$$

DeMarco et al., PMB (2005)

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- Scanning protocols