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Determination of MC-based predictive models for personalized and fast kV-CBCT organ dose estimation

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Introduction and objective

The intensive use of CBCT during radiotherapy treatments induces additional radiations doses delivered on large volumes. If those doses are often neglected, the medical community is starting to ask for an accurate dosimetric tool dedicated to kV-CBCT.

The aim of the present study is to develop a Monte Carlo-based organ doses calculator suitable for clinical environment. To ensure fast dose estimation, the possibility to determine predictive models based on patient morphology was studied.

Material and method

1. Development of a kV-CBCT simulator

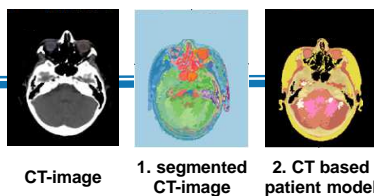
- A XVI kV-CBCT (Elekta) simulator was developed using the MC code PENELOPE [1].
- The XVI acquisition simulator was validated against experimental data [1] [2].



- The X-ray tube (electron source and anode)
- The different collimators
- The Bowtie filter (F1)

2. Realization of personalized 3D dose calculation

- Personalized 3D-dose calculations were performed using planning CT-images :



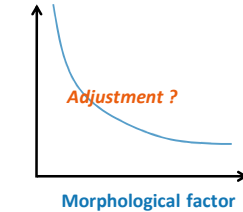
Integration in the MC simulator to perform personalized 3D dose calculation

- CT-images were segmented by a statistical process based on ddCRP algorithm [3].
- To ensure accurate kV-beam dose calculation 5 to 7 soft tissues and 10 bones were used for the patient models.

3. Determination of organ doses predictive models

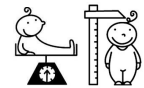
- A cohort of 40 children aged from 1 to 18 years and 10 adults was constituted.
- Dose maps were calculated for each patient and various kV-CBCT protocols (Tab. 1) while respecting equivalent simulation conditions : patient and isocenter positions.
- Doses to critical organs were extracted and correlation with morphologies were studied.

Organ dose



Several morphological factors were tested :

- Age, weight, size, body mass index (BMI)
- Dimensions of the imaged volume : larger, thickness, circumference
- Femoral head distance



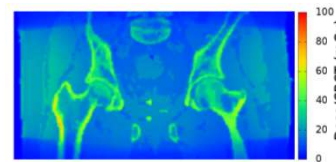
Tab. 1 : Acquisition parameters for kV-CBCT acquisitions

	Tension	mAs/proj	Collimator	Filter	Projections	Start/end
Pelvis	120 kVp	2.56	M15	Bowtie (F1)	660	-180°/180°
Head & neck	100 kVp	0.1	S20	F0	360	-135°/70°
Thorax	100 kVp	1.6	M15	Bowtie (F1)	660	-180°/180°

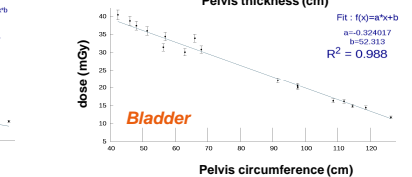
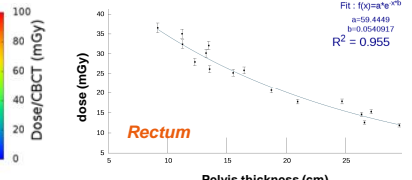
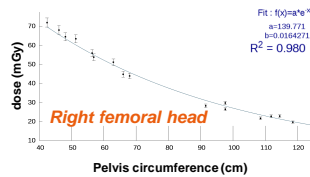
Results

- Except for the head-and-neck localization, results show dose variations highly correlated with the patient morphology. Doses received by children (small morphologies) are 2 to 3 times higher than doses received by adults.
- Doses to organs at risk can be adjusted with morphologic parameters directly measured on the planning CT using linear or exponential functions (Ex. 1).
- For the head-and-neck localization (Ex. 2), organ doses are little affected by morphology because of the semi-rotational acquisition process (200°) and the slight head and neck size variations with age (Ex. 2). In this case, the mean organ dose for all the cohort might be a sufficient dose estimator for every morphology (Tab. 2).

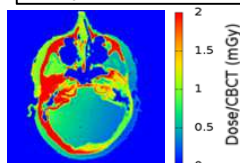
Example 1 : pelvis localization



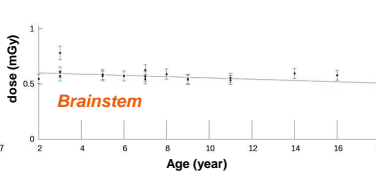
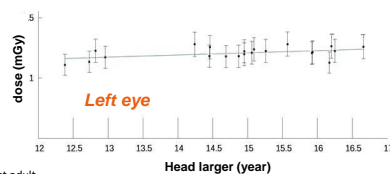
Example of a dose distribution for a normal weight man



Example 2 : head and neck localization



Example of a dose distribution for a normal weight adult



Tab. 2 : Mean organ doses for all the cohort

Organ	Dose (mGy)	Standard deviation (mGy)
Left eye	1.21	0.05
Brainstem	0.58	0.08
Thyroid	1.04	0.08
Brain	0.64	0.07
Left cochlea	2.33	0.41

- Limitation :** the impact of isocenter position variations was not study in this work.

Conclusion

This preliminary cohort study demonstrates the possibility to determine mathematical predictive models for personalized and fast kV-CBCT organ dose estimation. Future work will include an extension of the patient cohort to increased the accuracy of the mathematical adjustments and a similar study for the OBI kV-CBCT (Varian). Those perspectives are a part of the French National Research Agency (ANR) project AID-IGRT.

[1] H. Chesneau et al. "Monte Carlo simulation for imaging dose estimation: application to the Elekta XVI kV-CBCT." ESTRO annual meeting 34, Barcelona 2015.

[2] H. Chesneau et al. "Comprehensive validation of a Monte Carlo kV-CBCT model using OSL and spectral measurements." ESTRO annual meeting 35, Torino 2016.

[3] S. Ghosh et al. "Spatial distance dependent Chinese restaurant processes for image segmentation." Advances in Neural Information Processing Systems Proceedings Books, 2011.