Comparison of analytical and Monte Carlo calculations for heterogeneity corrections in LDR prostate brachytherapy

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PURPOSE

- Heterogeneities have a significant influence on low energy (LDR) brachytherapy
- Develop algorithm for dose calculation in prostate with calcifications
  - accounts for effect of heterogeneities
  - based on TG-43 reference data
  - real-time calculation speed
- Compare performance of algorithm vs Monte Carlo (MC) simulation
  - dose reliability
  - computing speed
- Assess suitability of algorithm inclusion in clinical commercial treatment planing system (TPS)

MATERIALS & METHODS

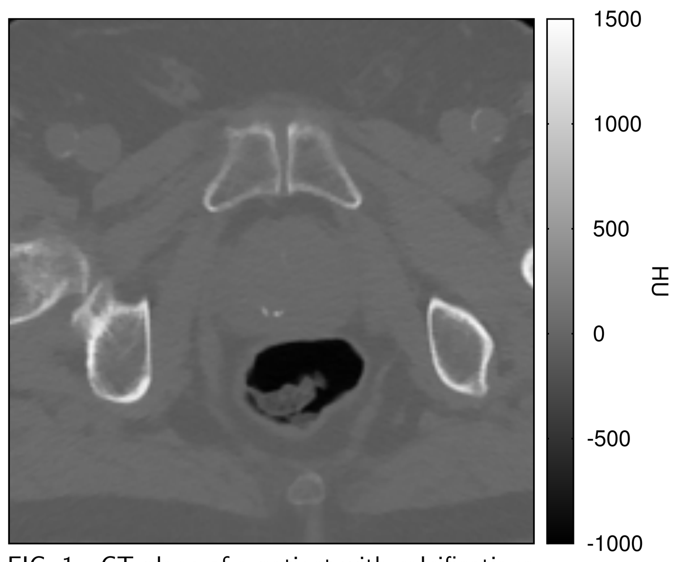


FIG. 1 - CT plane of a patient with calcifications inside the prostate (La Fe-Hospital).

- $HU \leq 100 \Rightarrow$ Water
- $HU > 100 \Rightarrow$ Calcification

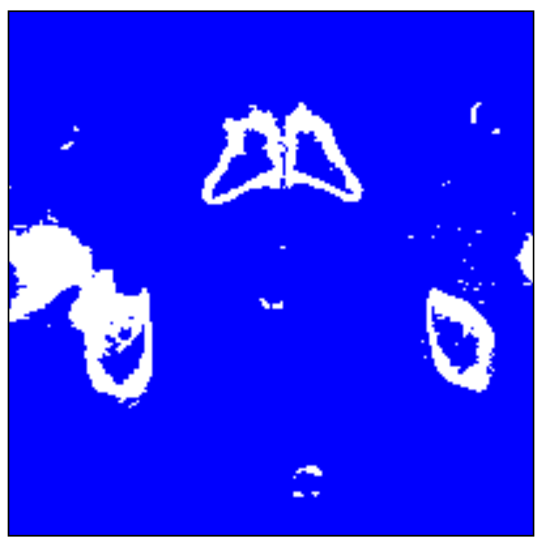


FIG. 2 - Tissue type (Water-blue, Calcification-white) according to the calcification threshold at 100 HU.

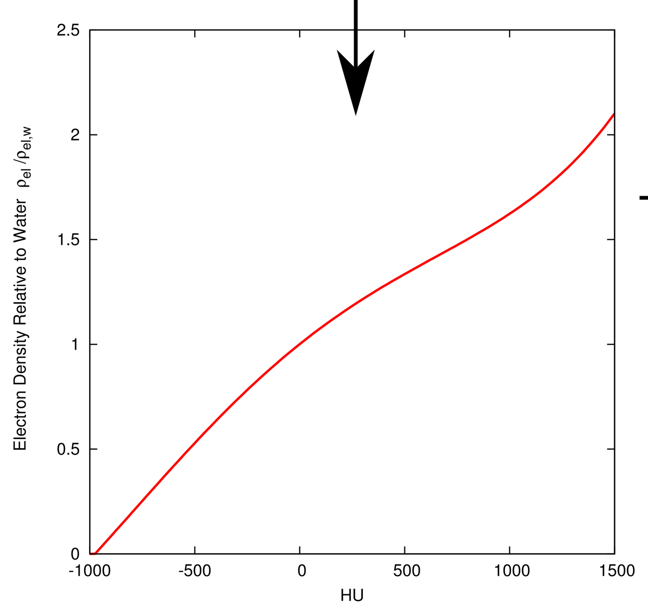


FIG. 3 - Calibration curve of HU number to relative electron density (La Fe-Hospital).

$$\text{Mass Density} = \frac{\rho_{el}}{\rho_{el,w}} * \begin{cases} 1.0\,\frac{g}{cm^3} & \text{if Tissue} = \text{Water} \\ 0.9\,\frac{g}{cm^3} & \text{if Tissue} = \text{Calcification} \end{cases}$$

Voxelized phantom characterized by { **Tissue type**, **Mass Density** }

Monte Carlo Simulation (PENELOPE2009)

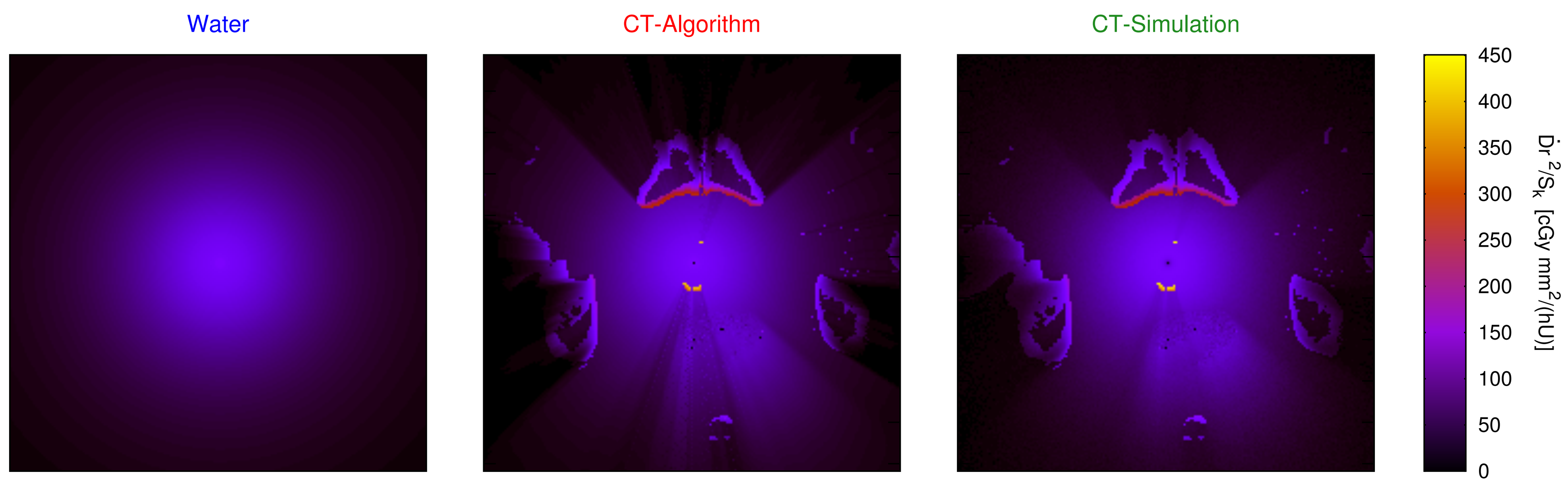
- At the center of the plane, one ^{125}I seed is simulated
  ↪ Model 6711-OncoSeed™, manufactured by Amersham-Health
- For each voxel:
  ↪ The mass density ρ is specified
  ↪ A composition is defined depending on tissue type

Analytical algorithm

- Input: Radial dose function $g(r)$, Dose rate constant Λ, Air-kerma strength S_k
- For each voxel:
  ↪ The mass density ρ is specified
  ↪ A mass absorption coefficient (μ/ρ) is defined depending on tissue type
  ↪ The distance r to the radioactive seed is computed
- Based on the water-equivalent path method: $\Delta r_{eq} \propto \Delta r \, \frac{\rho}{\rho_w} \frac{(\mu/\rho)}{(\mu/\rho)_w}$
- Fundamental idea: released energy $E\Big|_r^{r+\Delta r} = E_w\Big|_{r_{eq}}^{r_{eq}+\Delta r_{eq}}$; $E \propto \int g(r')dr'$
- Ray-tracing across the phantom is required (length of intersections)

RESULTS

FIG. 4 - Dose rate by air-kerma strength times the squared distance to the radioactive seed, which is placed at the center of the imaging plane. Heat maps for the homogeneous/Water and heterogeneous/CT cases (Algorithm and Simulation) are shown in a common color scale range for a reliable comparison.



- Significant impact of calcifications in dosimetry with respect to homogeneous case
  - Higher dose in calcificated regions (hot spots) due to higher absorption coefficient
  - Lower dose behind calcificated regions (shadows) due to energy conservation
- Remarkable agreement Algorithm - Simulation (see FIG. 4 and FIG. 5)
  - 5A: Dose 'shadow' effect caused by two prostate calcifications between seed and calculation point
  - 5B: Dose 'hot spot' effect in a prostate calcification (first peak) and surrounding bones (last peaks)
  - 5C: Dose 'overflow' effect produced by an air cavity (see FIG. 1)
- Computation performance (1 seed, 201×201 voxels): Algorithm 0.16 s ⇔ 108 h Simulation (10^9 events)

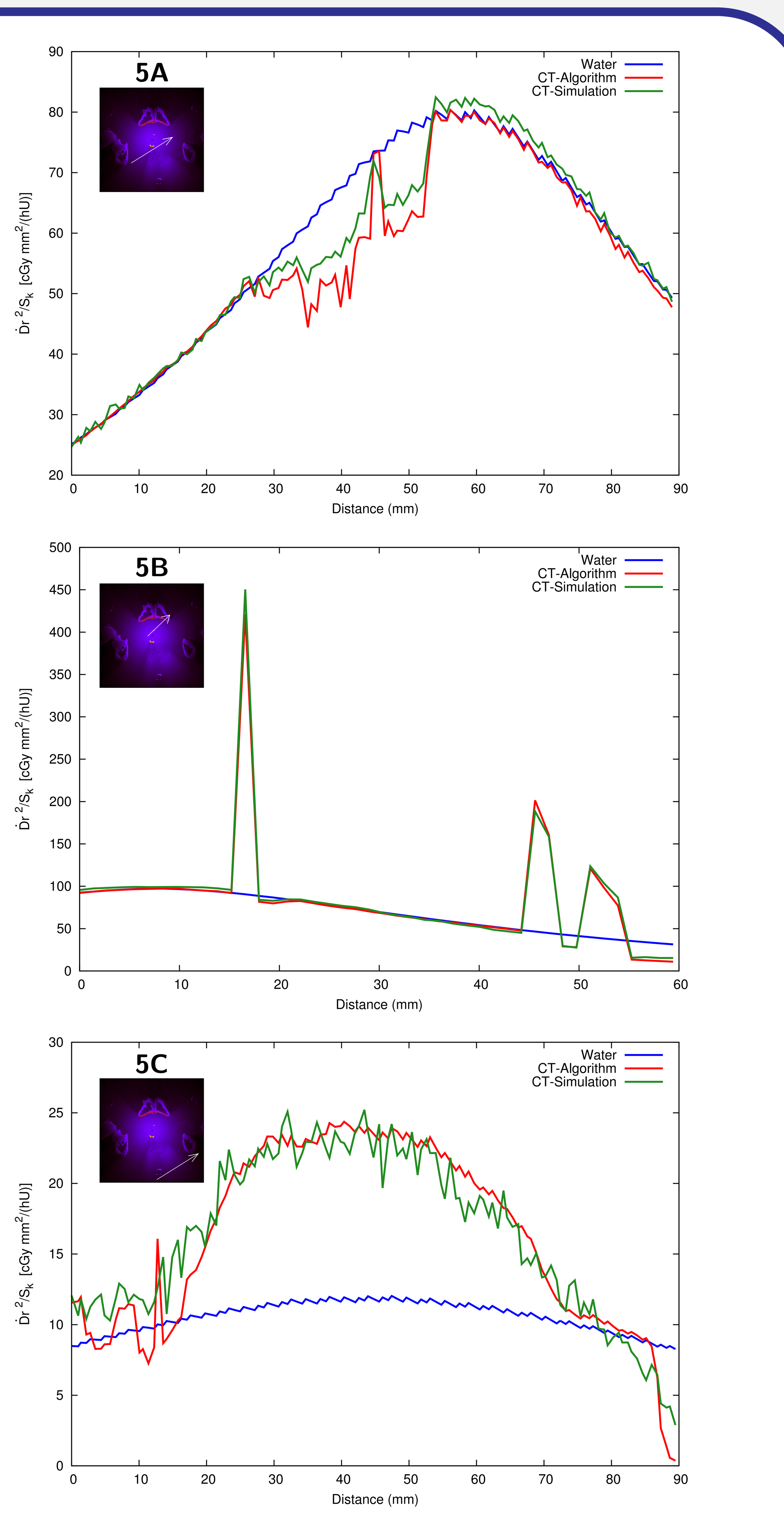


FIG. 5 - Line profiles of the dose rate by air-kerma strength times the squared distance, drawn across the imaging planes of FIG. 4 (white arrows in the insets) for three cases of interest.

TAB.1 - Conclusions about the weaknesses, strenghts, and challenges regarding the analytical dose calculation algorithm presented.

Weaknesses	Strengths	Challenges
• Non-scatter assumption • Ray-tracing artifacts	• Simple, fast and robust • Agreement with simulation • Applicable to any heterogeneity	• Accuracy of tissue classification • Energy dependent absorption coefficient

OUTLOOK

↪ **Improvement of treatment quality**
↪ **Suitable for clinical real-time TPS**