A method for estimating the effect of density changes on particle range using water equivalent path length

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Introduction

- The precision of particle therapy is sensitive to changes in density in the particle path.
- The difference in the water equivalent pathlength (WEPL), from planning CT (pCT) to the anatomy of the day, allows for an estimation of the effect of density changes on particle range.
- However, $\Delta\mathrm{WEPL}$ assumes the point of calculation origin is anatomically the same on both CT modalities.
- This study therefore aims to provide a method for estimating the effect of density changes to the dose distribution, without the need for a full dose recalculation.

Method

- The method used two images modalities, the pCT and a CT-like image of the day (dCT), which were both translated to stopping power values.
- The iso-dose of a given beam was extracted from the plan as physical points ($P_{\mathrm{iso-dose}}$) in pCT space (P_{pCT}).
- We assumed that the pCT field configuration had the same physical positions in dCT space.
- From each point in $P_{\mathrm{iso-dose}}$ the WEPL was calculated as the sum of linearly interpolated values ($S_{\mathrm{pCT}}(p)$), at each step along the opposite beam direction (b), until the edge of the image:

$$\mathrm{WEPL}_{pCT} = \int_0^{p_{\mathrm{edge}}-p_0} S_{\mathrm{dCT}}(p_0+t)dt, \qquad \text{where}: \quad t = xb, \{x \in R, x = 0\} \wedge p_0 \in P_{\mathrm{iso-dose}}$$

$$\mathrm{WEPL}_{pCT} = \sum_{\substack{(p_0+isb)\in P_{\mathrm{pCT}} \\ i=\{1,2,\dots\}}} S_{\mathrm{pCT}}(p_0+isb)\cdot s, \qquad \text{for} \quad s \to 0$$

- Taking the same $P_{\mathrm{iso-dose}}$ from the pCT and calculated the intersection, p_{edge}, in the direction of b, with the nearest bounding plane of dCT.
- Accumulated from pedge stepping in the $-b$ direction until $\mathrm{WEPL}_{\mathrm{pCT}}$ was reached, and thus pfinal, satisfying:

$$\mathrm{WEPL}_{\mathrm{pCT}} = \int_0^{p_{\mathrm{edge}}-p_{\mathrm{final}}} S_{\mathrm{dCT}}(p_{\mathrm{edge}}-t)dt, \qquad \text{where}: \quad t = xb, \{x \in \mathbb{R}, x \geq 0\}$$

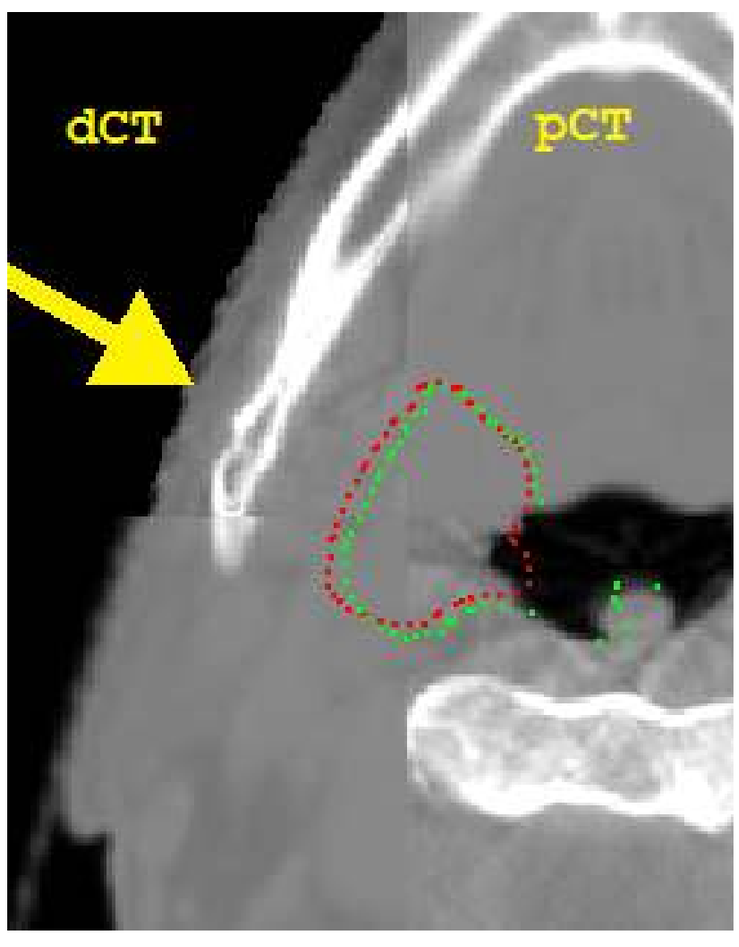
Results

The visual representation on the right shows:

- The original structure, in red, from the pCT
- The WEPL-structure, in green recalculated on the dCT

The dCT is a cone-beam CT in this example.

Visual example



Conclusion

- Our method produces a per-beam pseudo-iso-dose on the dCT
- I.e. an estimate of the per-beam iso-dose if recalculated on the dCT.
- We have implemented this method with scatter-corrected CBCTs.

Open source

`https://gitlab.com/agravgaard/CbctRecon`