Title:
A quantitative evaluation of computational paediatric phantoms for radiotherapy applications

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Purpose
Computational phantoms have important applications in paediatric radiotherapy, in quality assurance of diagnostic/therapeutic protocols, and in reconstructing historical radiation doses. Detailed age-specific computational anatomical models are available, developed from average and/or healthy individuals, which may not be representative of cancer patients due to pathology and/or treatment effects. This study investigated the capability of existing phantoms in representing the paediatric radiotherapy population.

Methods
Computational models evaluated were the International Commission on Radiological Protection (ICRP) paediatric reference computational phantoms (n=8, median age 8y, range: 1–15y) and the default 4D extended cardiac torso (XCAT) (n=75, median age 9y, range: 1–18y). Five key organs (kidneys, lungs, spleen, liver and brain) were automatically segmented on the virtual phantoms similar to clinical organ at risk segmentation protocols. Anatomical similarity was assessed in terms of organ length and mass. These quantities were measured on the phantoms and on a clinical radiotherapy dataset, consisting of planning CT images/contours from craniospinal irradiation patients (n=68, median age 7, range: 2–16y). We also compared clinical measures with published literature on healthy children (9 publications, median age 8y, range 1–16y).

Results
For each dataset (phantom, published and clinical data) we performed a linear fit of the mass and length across the ages. Differences between clinical data and virtual phantoms/published data were calculated as the average relative difference between the linear fits for integer ages across the clinical data. For the phantoms, differences across all organs ranged from 1–22% for lengths and 4–35% for masses. For published data these were 5–23% and 7–39%, respectively. The smallest and largest differences were found for the liver and spleen, respectively.

Conclusion
Quantitative anatomical differences were described between phantoms, literature, and routine radiotherapy data. Our findings will help selecting and tailoring the phantoms most representative of this population.

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Innovation/Impact: The key innovation of this work is the assessment of the usability of readily available paediatric phantoms for a cancer patient population. Representative phantoms are needed for quality assurance testing and must therefore be representative of the cohort it aims to model.

Key results: Differences were quantified for both lengths and masses of key organs by comparing computational phantoms and literature with clinical data. Table 1 demonstrates the differences between each dataset to the clinical data, highlighting that across the organs and the two measures, each had different strengths. An example of this is with the liver, considering the length the most comparable with the clinical data were the ICRP phantoms (0.9±0.5), whereas for the mass this was the XCAT phantoms (4.3±2.1).

Table 1- Relative differences in length and mass measurements for organs tested compared with clinical data. Note some comparisons were not made for published data as there were insufficient studies for comparisons to be made.

Mean relative differences (%)						
Organ	XCAT		ICRP		Published	
	Length	Mass	Length	Mass	Length	Mass
Spleen	9.5±4.3	23.1±17.1	9.3±6.8	34.9±10.5	23.2±2.3	39.2±8.6
Liver	3.7±2.3	4.3±2.1	0.9±0.5	7.6±0.5	14.7±5.9	12.4±4.2
Brain	8.8±0.3	12.3±2.2	3.4±2.5	14.3±1.86	N/A	14.3±5.7
Kidneys	18.6±1.6	19.4±10.3	22.4±5.2	3.7±3.7	5.0±2.4	7.0±0.7
Lungs	3.9±2.4	20.4±3.9	6.9±4.3	7.9±3.6	N/A	N/A

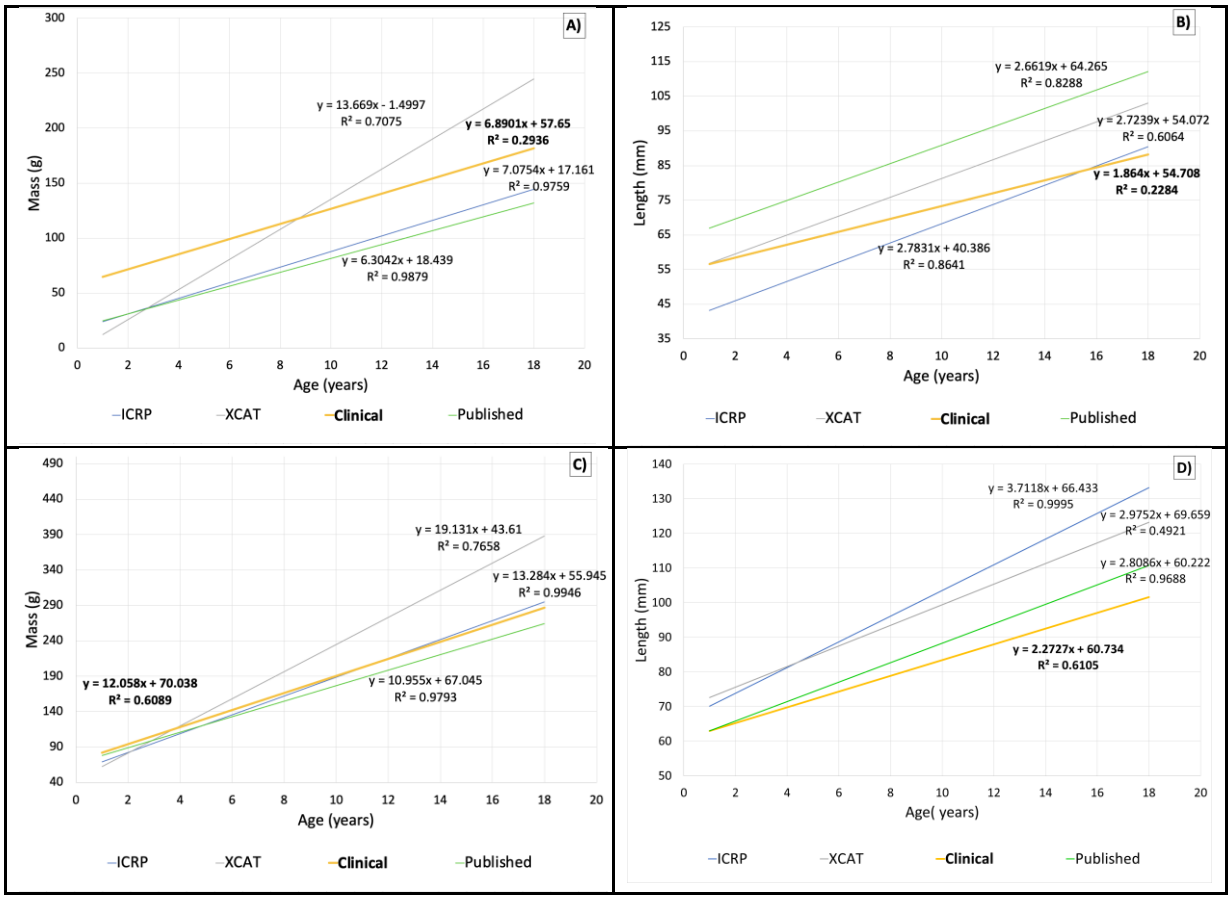

Figure 1: Plots showing age versus spleen mass (a) and length (b), and kidney mass (c) and length (d) for ICRP/XCAT computational phantoms, literature data and clinical data.