The road to accurate metal implant imaging for proton therapy: a comparison between photon counting CT, dual energy CT, and conventional CT

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Introduction

The treatment of cancer is a complex and multifaceted process, of which radiation therapy (RT) plays a crucial role [1]. **Metal implants** cause a significant challenge in obtaining accurate images of surrounding tissues for RT treatment planning system (TPS), due to the presence of image artefacts on CT scans. This study explores the potential of photon counting computed tomography (**PC-CT**) in reducing those metal artefacts in patients with metal implants undergoing **proton therapy (PT)** for head and neck cancer. Therefore, PC-CT is compared to dual energy CT (**DECT**) and conventional CT (**CCT**) combined with iterative reconstructions technique (iMAR), using a 3D-printed Ti6Al4V with known composition, density and shape. The aim is to map the differences between the three CT devices and post-processing technique, based on the **delineation** of the metallic object and **artefacts**, to estimate the metal-induced uncertainties to consider during RT TPS [2].

Methodology

A self-designed 3D metallic titanium (Ti6Al4V) object is placed in the water phantom under six angles described and shown in table 1 and figure 1. The measurements are performed with **three CT devices**: PC-CT, DECT, and CCT. The decision matrix for the imaging of the metallic object is shown in figure 2.

The CT images are qualitatively and quantitively assessed for the following angles: YZ 0°, YZ 90°, and XY 45°. The qualitative assessment involves rating the delineation of the metallic object and presence of artefacts on a scale from 0 to 3 and C to A, respectively as shown in table 2 and 3. In the quantitative assessment, length measurements and ROIs are analyzed.

Table 1: Angles of the metallic object in the water phantom

Plane	Angle (°)		
YZ	0°	45°	90°
XY	0°	45°	
XYZ	45°		

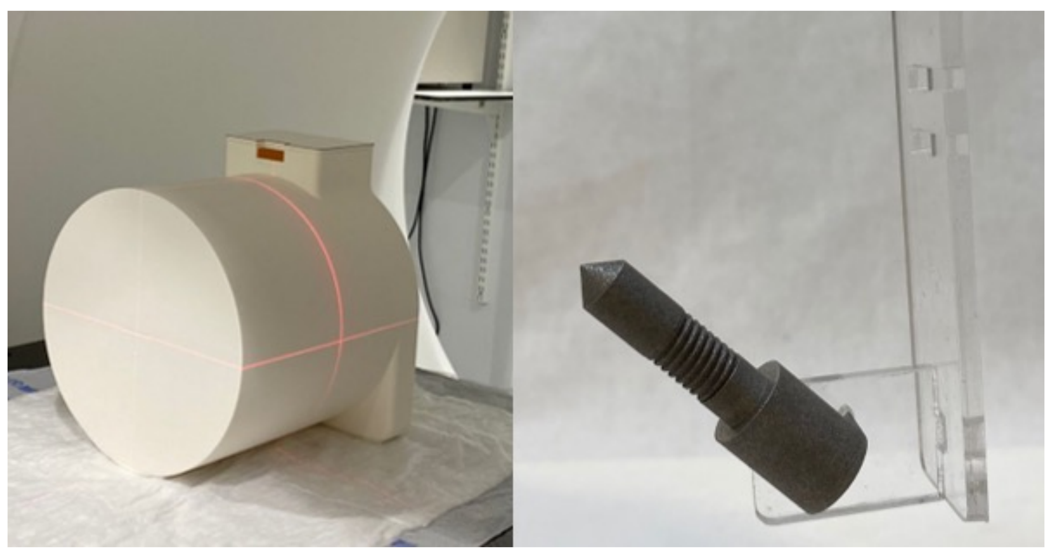

Figure 1: Experimental set-up with a Ti6Al4V metallic object in YZ 45° position

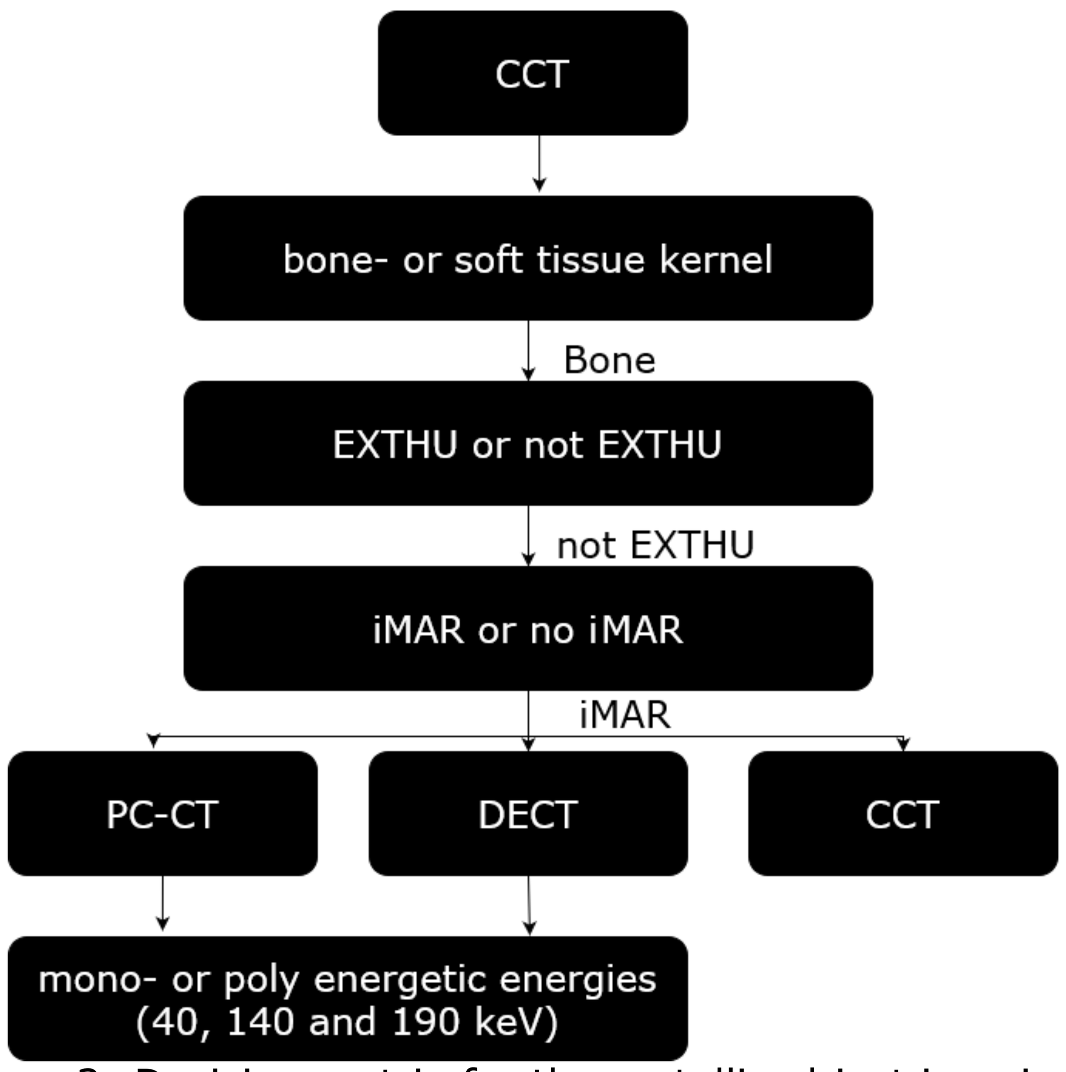

Figure 2: Decision matrix for the metallic object imaging

Table 2: Visual score table for the delineation of the 3D metallic object on the CT-images

Visible but not delineable	0
Visible and limitedly delineable, including only rough structures	1
Visible and delineable everywhere excluding fine structures (screw, tip)	2
Visible and delineable everywhere including fine structures (screw, tip)	3

Table 3: Visual score table for the presence of artefacts on image quality surrounding the 3D metallic object

Metal artefacts visible surrounding the 3D metallic object	C
Few to no metal artefacts visible surrounding the 3D metallic object	B
No metal artefact visible surrounding the 3D metallic object	A

Results

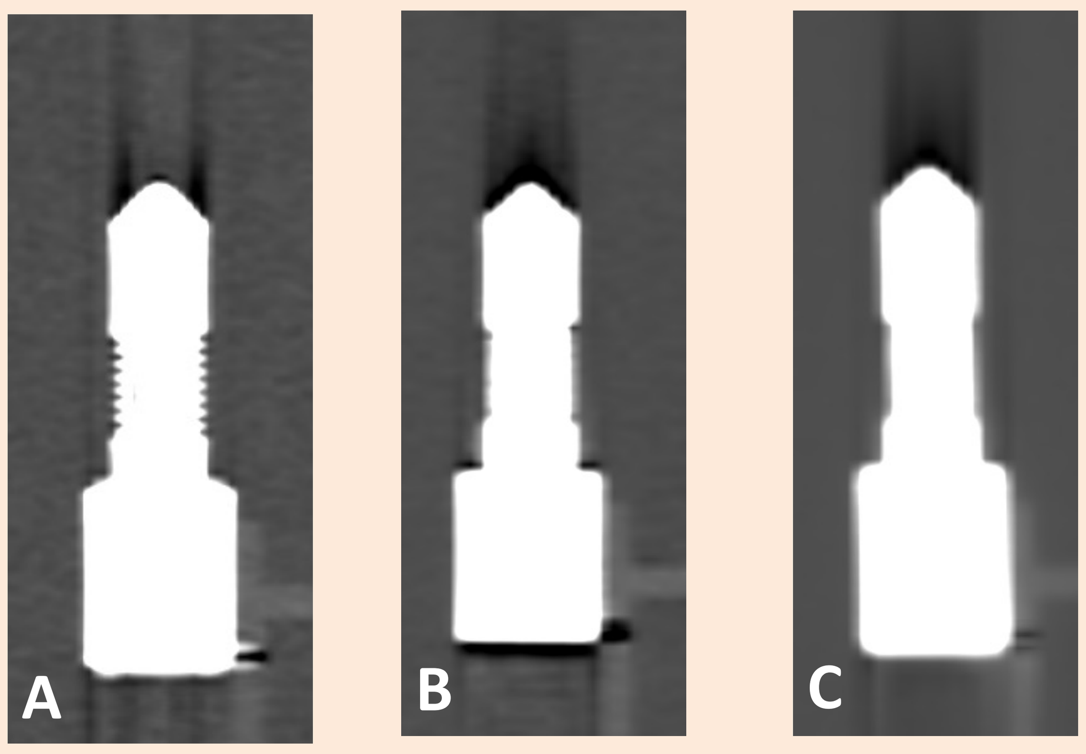

Figure 3: **Poly energetic image** of the metallic object on **PC-CT (A), DECT (B)**, and **CCT (C)** for the **XY 45°** plane with a slice thickness of 1 mm including iMAR

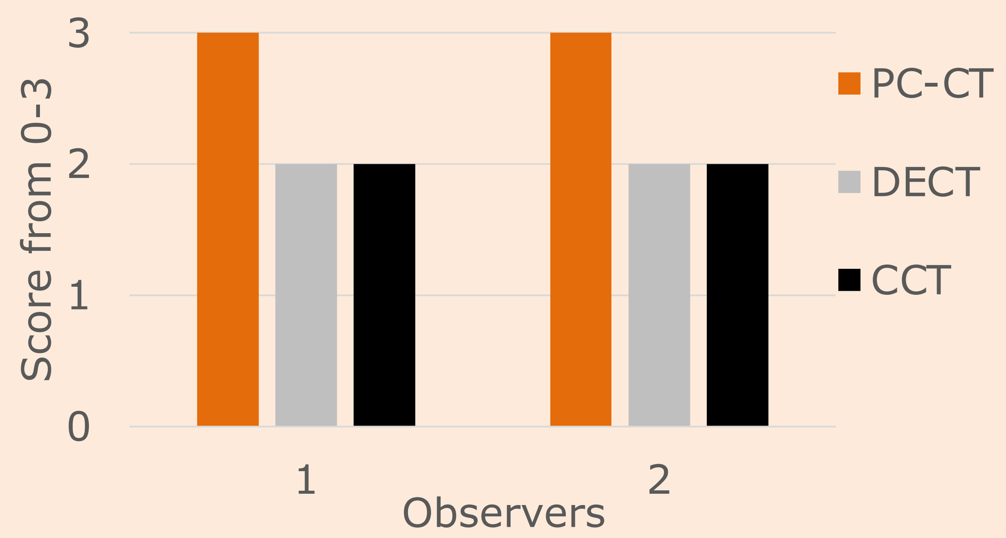

Figure 4: **Qualitative assessment** of poly energetic images with 1 mm slice thickness including iMAR on **PC-CT**, **DECT**, and **CCT** for the **delineation** of the metallic object of the plane XY and angle 45° with a score from 0 to 3

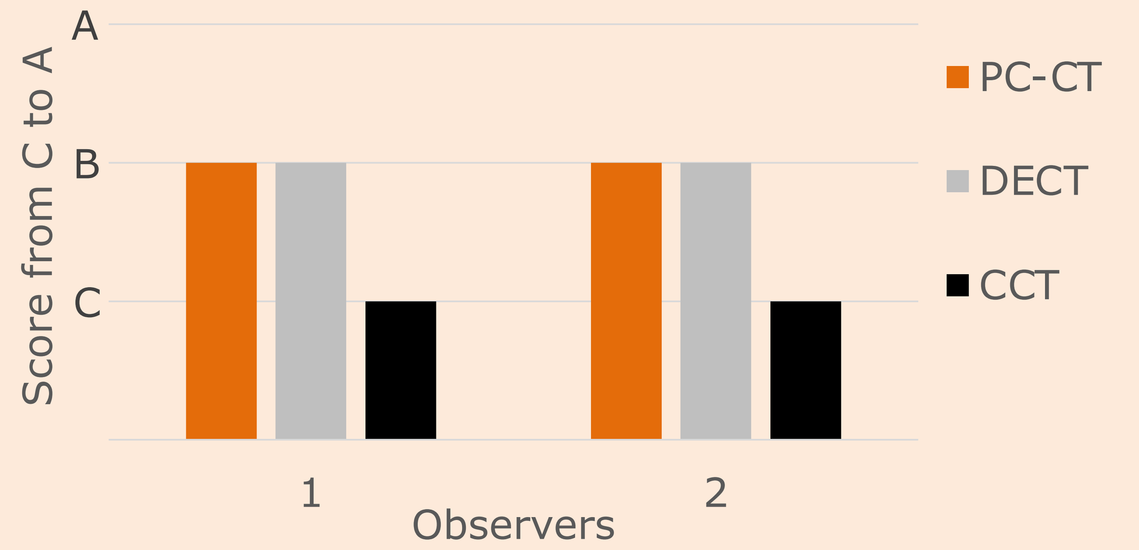

Figure 5: **Qualitative assessment** of poly energetic images with 1 mm slice thickness including iMAR on **PC-CT, DECT,** and **CCT** for the presence of visual **artefact** of the plane XY and angle 45° with a score from C to A

Conclusion

Based on the results, it can be concluded that PC-CT combined with iMAR yields superior performance compared to DECT and CCT in accurately delineating the fine structure of metallic implants. Additionally, DECT combined with mono-energetic techniques demonstrates enhanced efficacy in reducing metal artifacts compared to PC-CT and CCT. However, further research involving patients, other implant materials, and the impact on dosimetry is recommended to fully assess the potential benefits and limitations of these imaging techniques.

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[1] ICRU, „The International Commission on Radiation Units and Measurements,” *Journal of the ICRU*, nr. 10(1), pp. 1-94, 17 September 2010.

[2] H. Paganetti, „Range uncertainties in proton therapy and the role of Monte Carlo simulations,” *Phys Med Biol*, nr. 57(11), pp. R99-R117, 7 June 2012.