Reducing Cone-Beam Artifacts in Gamma Knife CBCT Images Using a Line-Arc-Line Scan Trajectory

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INTRODUCTION

Gamma Knife cone-beam CT (CBCT) images suffer from cone-beam artifacts, mainly towards the top of the head.

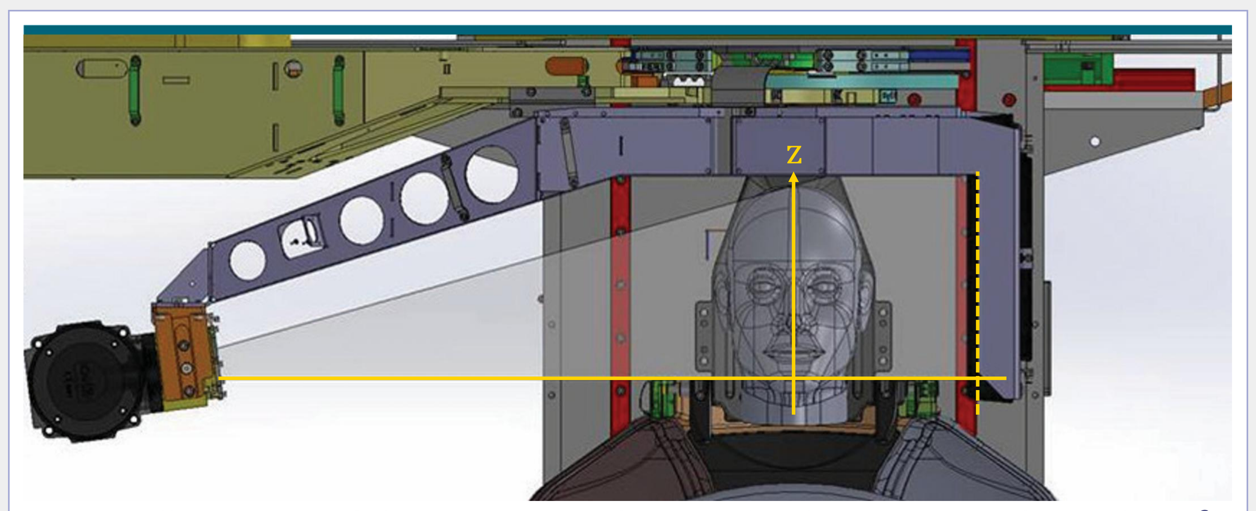

FIG. 1 – Illustration of the Gamma Knife CBCT (with permission from Elekta[3]).

Why ?

- Piercing point of the CBCT system located at the inferior edge of the detector, creating large cone-beam angles towards the top of the head (Fig. 1).
- Cone-beam artifacts caused by insufficient data sampling[1,2].
  - Circular scan : exact reconstruction only possible at the most inferior plane (x-ray beam is perpendicular to the detector). Towards the superior direction, the cone angle increases, and cone-beam artifacts appear with an increasing severity.

How ?

- A novel, optimized scan trajectory which improves completeness of data sampling will reduce cone-beam artifacts[4].
- Previous CBCT simulations[5] showed a line-arc-line trajectory is promising to reduce cone-beam artifacts.

Objective : conduct experiments on a Gamma Knife to (i) validate simulations and (ii) demonstrate the feasibility of the line-arc-line trajectory.

METHODS

- Gamma Knife compatible scan trajectories (Fig. 2) are combinations of :
  - Arcs : 200° rotation of the source around the z-axis
  - Lines : Translation of the patient table along the z-axis
- A mechanical stop prevents movement of the table away from the radiation unit beyond the current scan position. A custom setup (Fig. 3) is required to shift the head fixation backwards, freeing space at the front to move the table forward.
- Phantoms used: i) Catphan 503
  ii) anthropomorphic head
- Projections acquired for 200°-arcs at the most forward position in z and at 87.5 mm backwards of that position, and for lines of 175 mm at first and last gantry angles.
- CBCT images of different scan trajectories reconstructed using an iterative algorithm based on weighted least squares (from Elekta).
- Linear weight tapering applied on projections from their inferior edge, correcting for discrepancy in scatter when projections axially shifted.

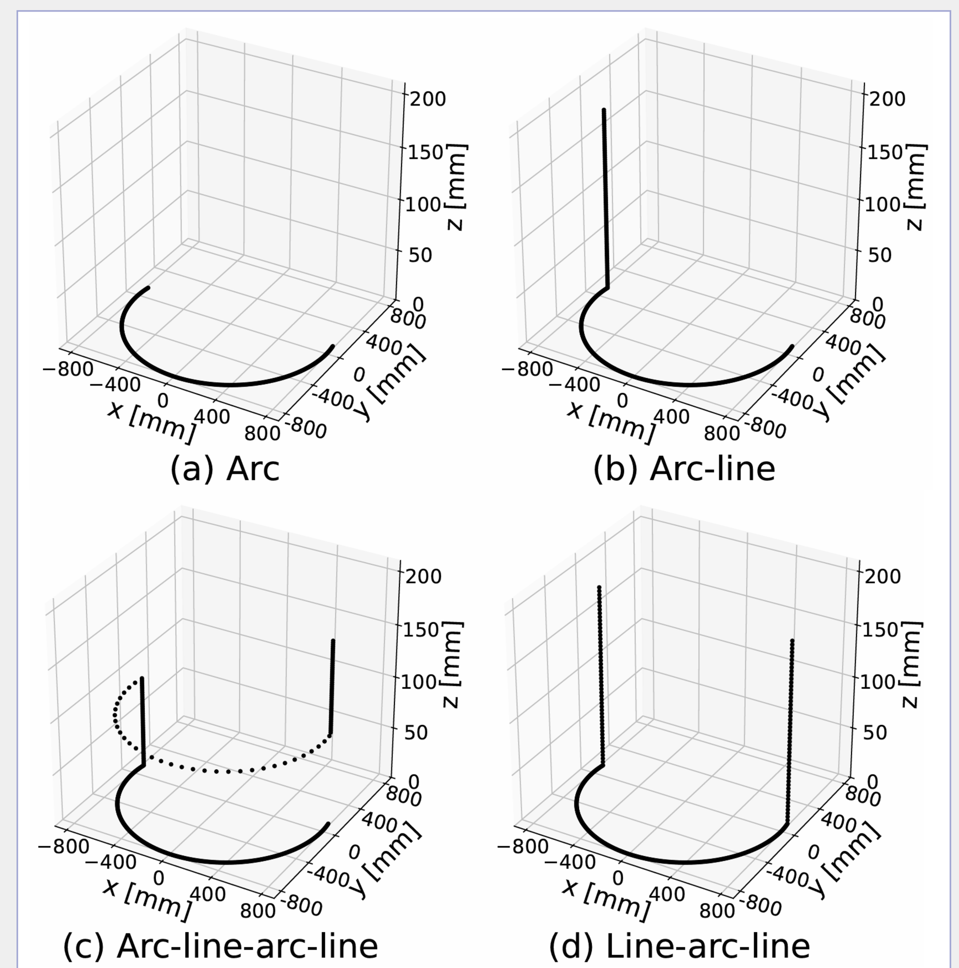

FIG. 2 – Selected scan trajectories investigated, where z is the axial axis.

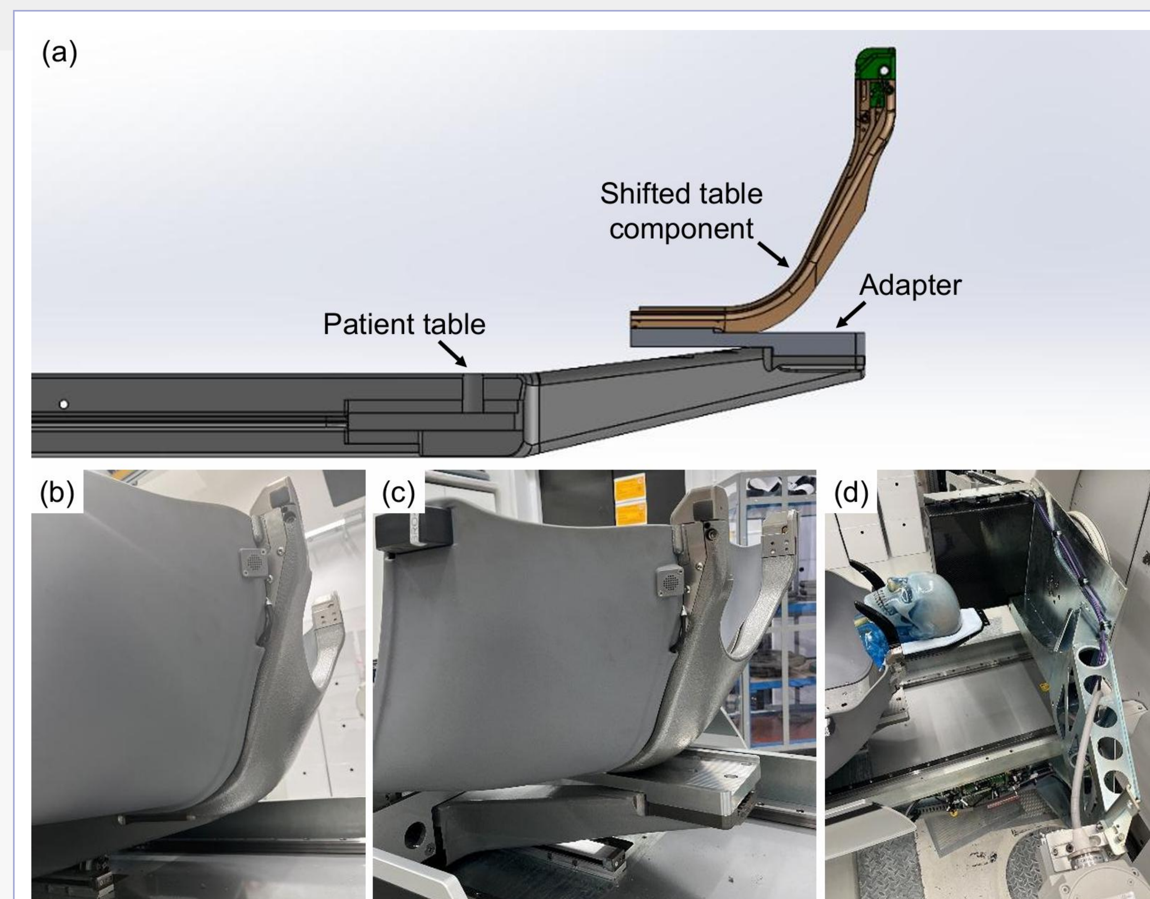

FIG. 3 – Gamma Knife setup used in this study. (a) digital schema of the setup with the adapter. Photos show the patient table in (b) standard configuration and (c) custom configuration, and (d) patient table with a head phantom at the most backward position in z in the custom setup.

RESULTS & DISCUSSION

CBCT reconstructions of the Catphan (Fig. 4) and the anthropomorphic head (Fig. 6) show that the line-arc-line trajectory achieves the best image quality among the investigated scan trajectories, in terms of :

- Cone-beam artifact reduction with the line-arc-line trajectory :
  - All artifacts are virtually removed ;
  - Average axial profiles of the Catphan (Fig. 5) show sharper edges at the interface between modules. The superior edge of the phantom has a 20/80 width that improves from 6.4 mm to 0.5 mm, a 92% reduction.
- Uniformity improvement with the line-arc-line trajectory :
  - Reduction of artifacts inside soft-tissue regions near high-density structures.

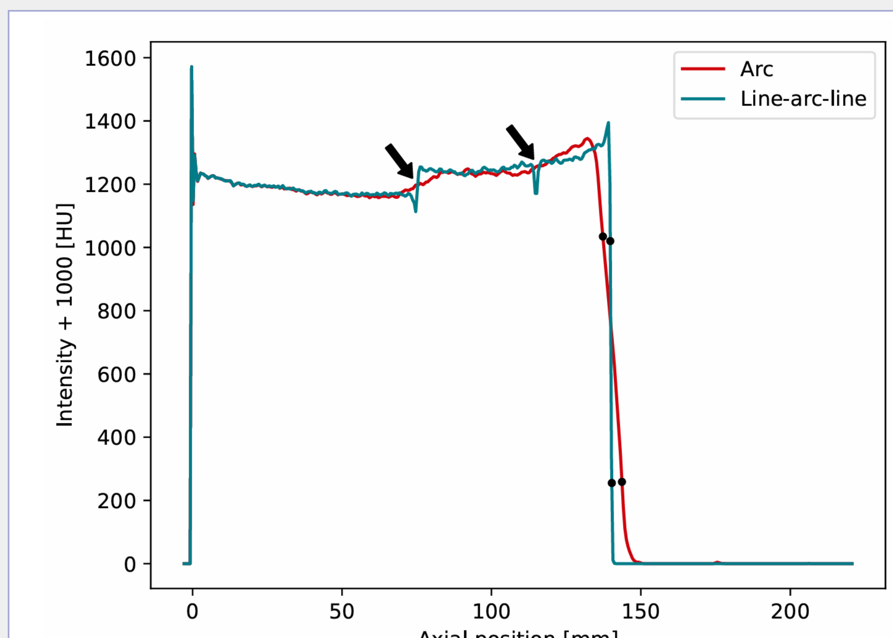

FIG. 5 – Average axial profiles of the CBCT images of the Catphan 503.

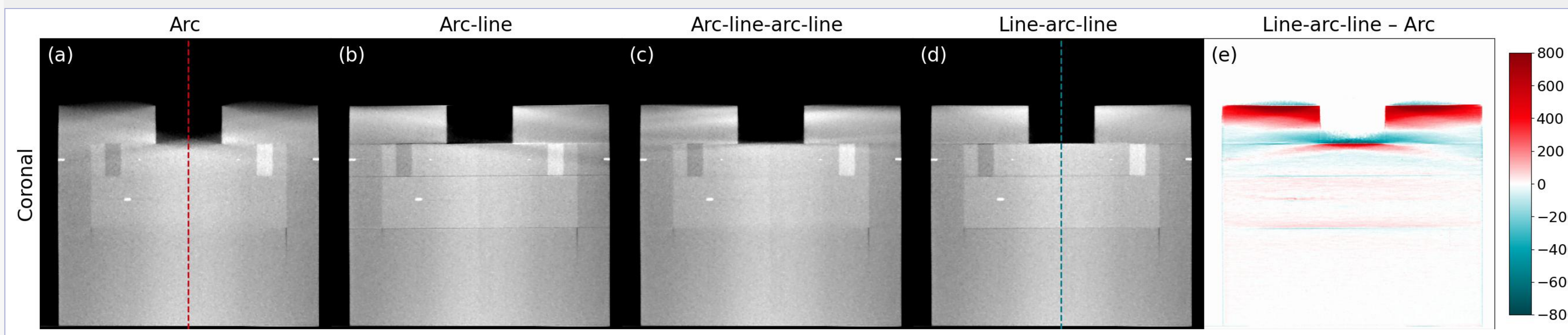

FIG. 4 – Slices from CBCT reconstructions of a Catphan 503 for different scan trajectories (window: [-1000, 500] HU), with the difference between the line-arc-line and arc trajectories in (e). Dashed lines indicate where the axial profiles are taken.

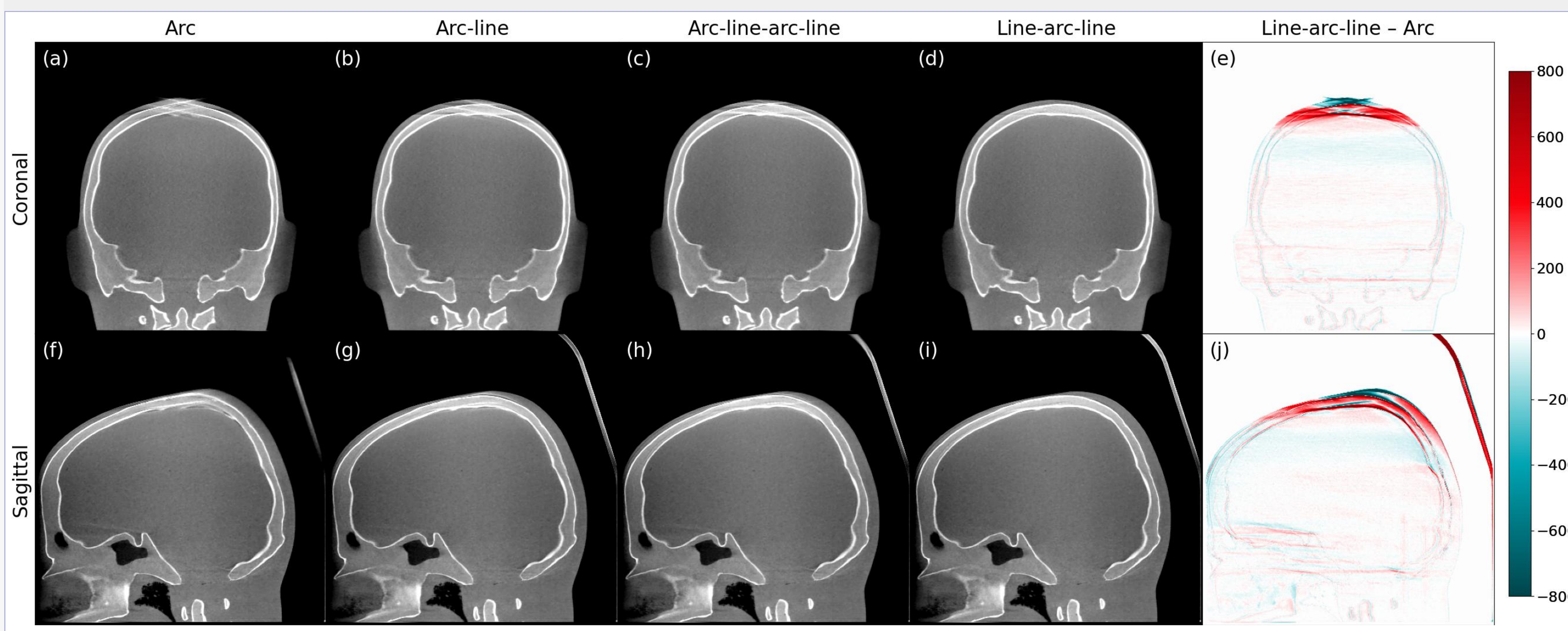

FIG. 6 – Slices from CBCT reconstructions of an anthropomorphic head phantom for different scan trajectories (window: [-1000, 1500] HU) , with the difference between the line-arc-line and arc trajectories shown in (e) and (j).

CONCLUSION

- Experiments on a customized Gamma Knife allowed the acquisition of CBCT projections along scan trajectories consisting of arcs and lines.
- Among the compatible scan trajectories, the line-arc-line gives the largest image quality improvement, mainly by reducing cone-beam artifacts.
  - The results confirm the previous theoretical work[5].
  - This trajectory requires moving the table before and after the standard arc, but it is reasonable to integrate into a clinical imaging workflow.
  - The proposed trajectory increases the number of projections by ~30%, increasing total imaging dose. A small reduction in dose per projection could allow to obtain a CBCT image without cone-beam artifacts and a slightly lower SNR, but with similar total imaging dose.

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