A multi-channel fusion cycleGAN for CBCT-based synthetic CT generation

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Pre-processing

- *Rigid registration*
- *Resample to 1x1x1mm*
- *Anonymization*
- *Mask*
- *Crop*
- Ensure image range [-1024, 3000]
- Mask correction
- Multi-channel range selection and normalization
- Pad/Crop to input size

CBCTs Centre C

Overflow correction

High-intensity values were captured in a ~40mm thick hull around the patient's exterior contour, created using a distance transform. High-intensity artefacts were replaced with air values (-1024 HU).

Multi-channel range selection and normalization

- Three channels for normalization: wide range, soft tissue (±100 HU for brain, ±150 HU for pelvis), high-density (>600 HU)
- Automated peak finder for CBCT soft-tissue channel
- Each channel independently normalized to [0,1] using min-max normalization

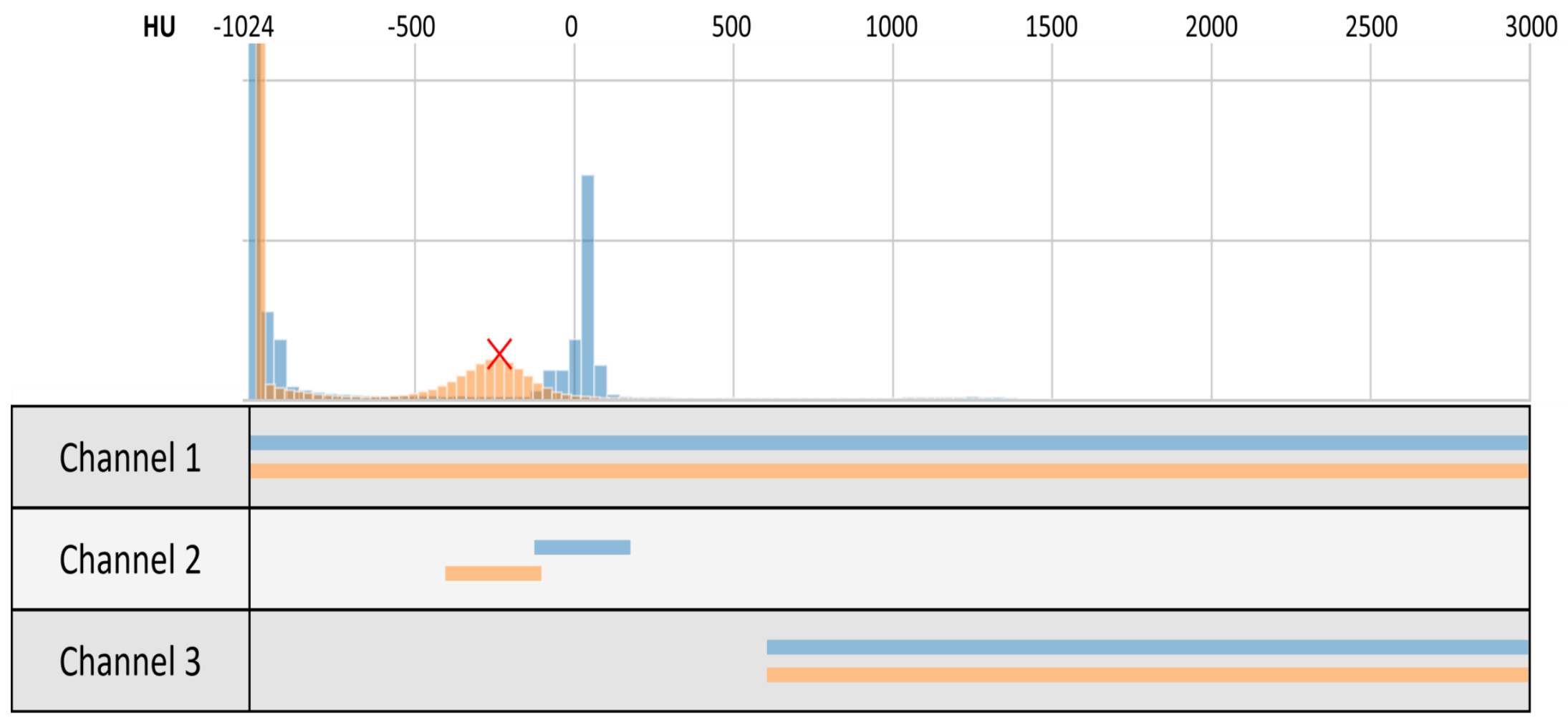
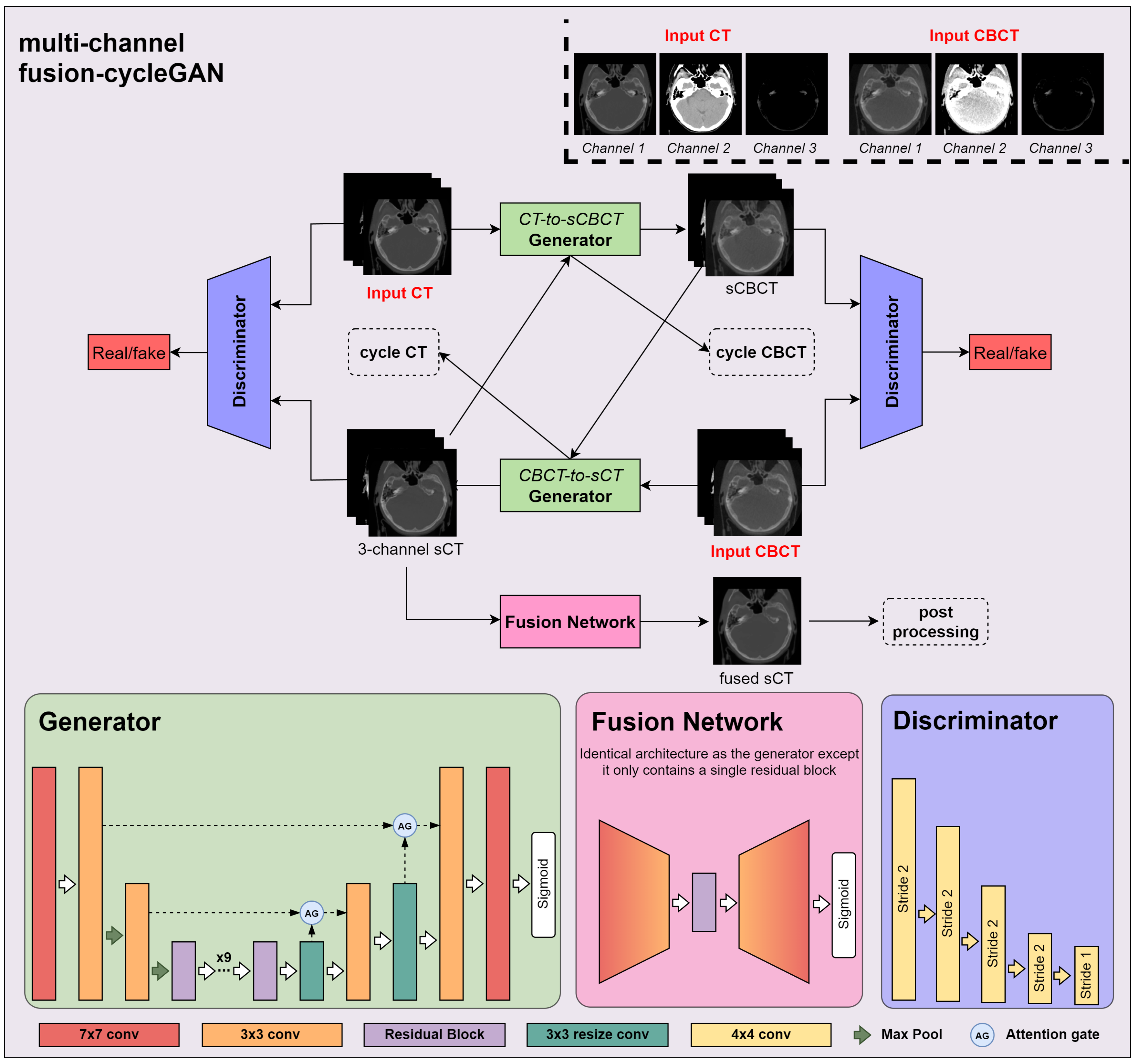


Figure 1: CBCT and CT image histogram for a pelvis scan shown with three input channel ranges. Red cross indicates CBCT soft-tissue peak.

Architecture & training protocol



Configuration	2D, unpaired with 3 channels
Input	Brain: 304x304 Pelvis 448x448
Data augmentation	none
Batch size	1
Maximum epochs	200
Optimizer	Adam
Initial learning rates	Generator: 0.0001 Discriminator: 0.0002
Learning rate decay schedule	After 5 epochs, decay both to 80% of learning rate every 2 epochs
Stopping criteria	Early stopping when the total generator validation loss does not improve for 20 epochs
Optimal model selection criteria	Optimal model is chosen based on best image similarity metrics calculated on train-time validation data
Loss functions	MSE on generators, BCE on discriminators
Training time	Brain: ~9hrs per epoch Pelvis: ~3hrs per epoch
GPU	Nvidia GeForce RTX 3090 with 24GB VRAM

Example Output

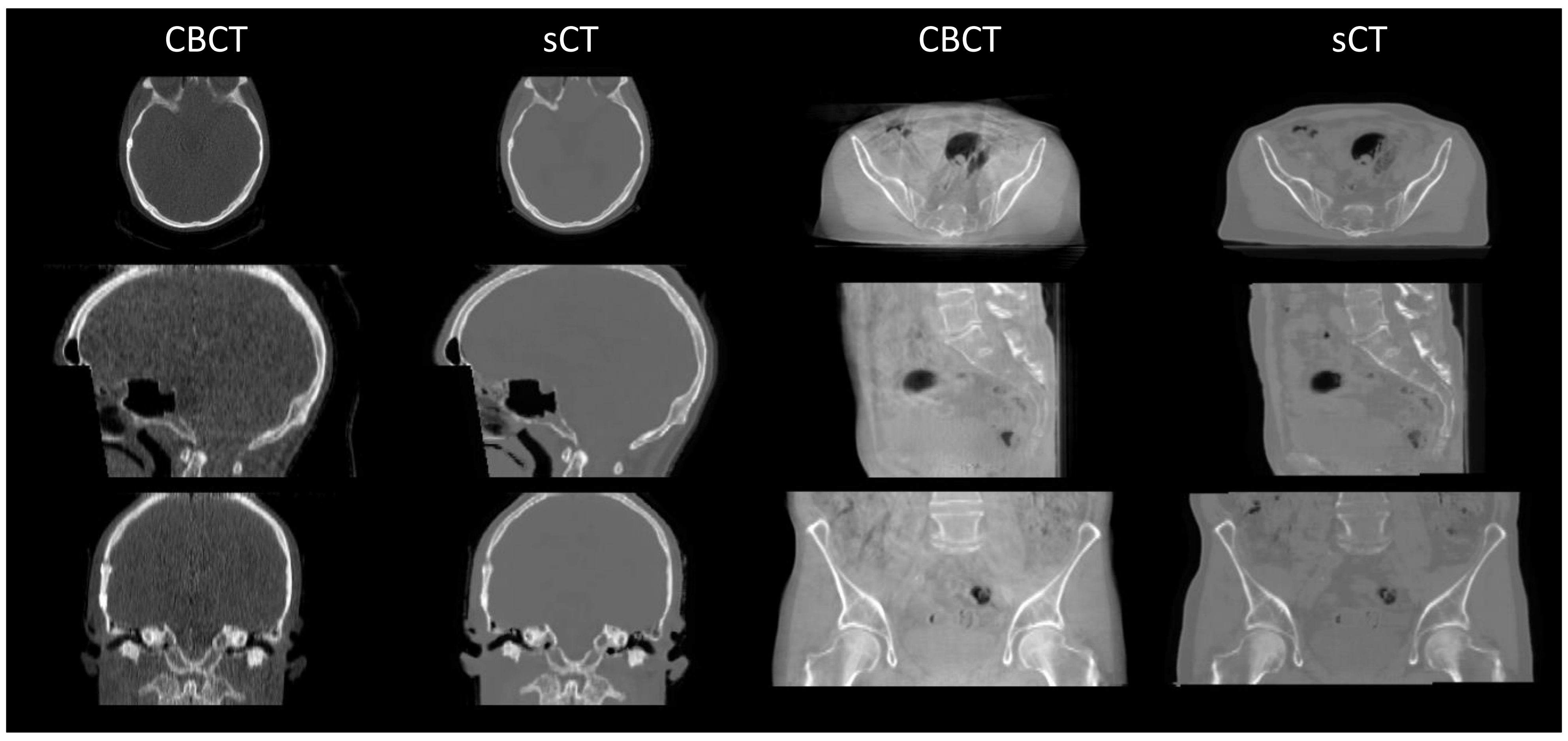


Figure 3: Example test phase CBCT and sCT generated by our methods. Pelvis and brain results are shown with HU scale of [-400,1200] and [250, 2500], respectively.

Channel fusion

The reference sCT (either full width/first channel for pelvis or fusion network sCT for brain underwent modifications based on specific conditions:

- Values within the narrow range were substituted with narrow channel values
- Values > 600 HU were replaced with dense channel values

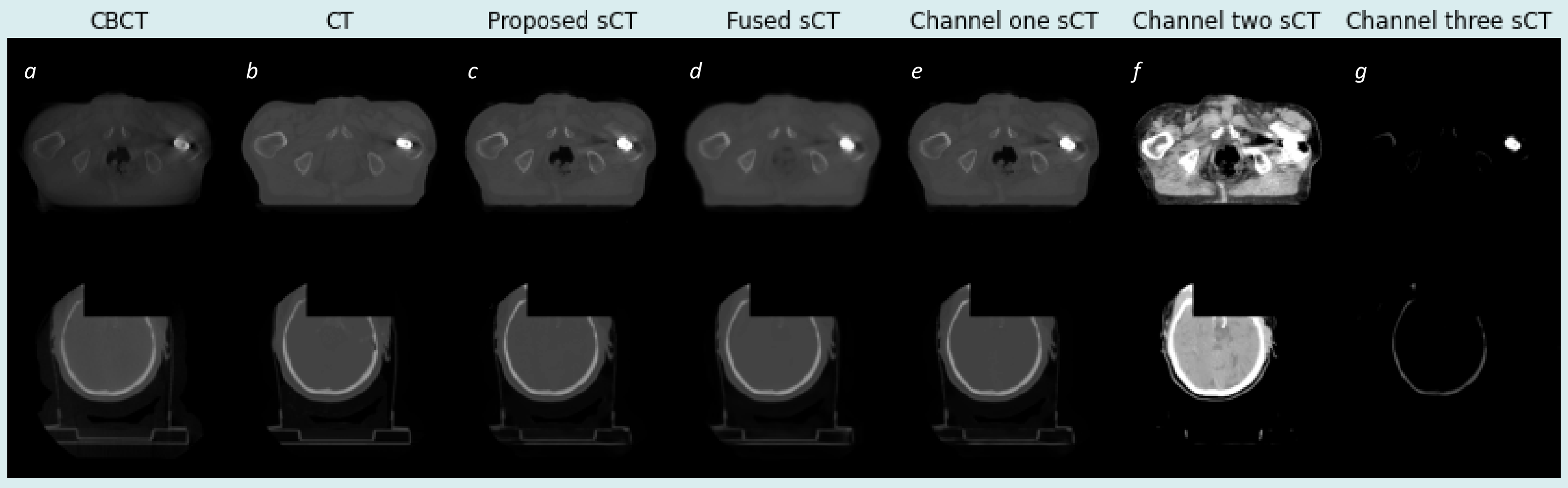


Figure 2: All available synthetic images; the proposed sCT, fused sCT, and individual channel sCTs, with input CBCT and ground truth CT. These images were generated during train-time validation. HU ranges: *a-e* [-1024, 3000], *f* [600, 3000] and g [-150, 150] and [-100, 100] for the pelvis and brain, respectively.

Metrics

Image Similarity

Phase	MAE (HU)	SSIM	PSNR (dB)
Validation	71.83 ± 15.00	0.86 ± 0.05	28.44 ± 1.85
Test	71.58 ± 13.79	0.86 ± 0.04	28.34 ± 1.50

Dose Evaluation

	DVH (%)	$\gamma_{2\%,2mm}$ (%)	$\text{MAE}_{target\ dose}$
Photon	0.07 ± 0.15	98.42 ± 4.94	0.01 ± 0.01
Proton	0.27 ± 0.27	92.32 ± 5.87	0.07 ± 0.05

Conclusions

The integration of multi-channel input with varying window/levels effectively addresses various challenges found in CBCT images.
This results in notable improvements, including improved preservation of soft tissue details, suppression of artefacts such as streaking, and accurate representation of daily patient anatomy.

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