3D MR Image Synthesis using Unsupervised Deep Learning Algorithm in MS Patients

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BACKGROUND

Clinical MRI scans typically exhibit significant image heterogeneity between timepoints, representing a major barrier for quantitative post-processing analysis. Deep learning image synthesis methods can be used to generate standardized images from any clinical images without losing patient information. Generative adversarial networks (GAN) are useful methods for image-to-image translations in computer vision applications. We present an implementation of an unpaired GAN for image-to-image translation of T1-to-FLAIR-weighted MR images and vice versa.

OBJECTIVE

To generate synthetic 3D whole brain Fluid-Attenuated Inversion Recovery (**FLAIR**) 1x1x1 mm^3 images from acquired 3D T1 MR images of MS subjects while preserving lesion information.

METHODS

- 465 unique MS brain T1/FLAIR un-registered pairs ('unsupervised') acquired at 3T were used to train our learning algorithm. Skulls were removed, each pair is co-registered to assist a pixel to pixel correspondence in the validation step. We used Cycle-Consistent GAN (**Figure 1**), an unsupervised deep learning method, to generate whole brain 3D synthetic images.
- For validation purposes, six methods were implemented to investigate the quality of synthesized images; Difference map, Histogram overlap, Mean Absolute Error (MAE), Peak Signal to Noise Ratio (PSNR), Mutual Information (MI) and Structural Similarity Index (SSIM). Comparisons were calculated between synthetic images as output and the acquired co-registered images as ground truth. To mitigate variations between input/output pairs, all slices were normalized by subtracting

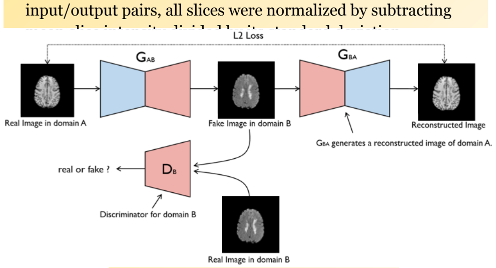

Figure 1. Simplified view of the Cycle-GAN network architecture

Results and Validation

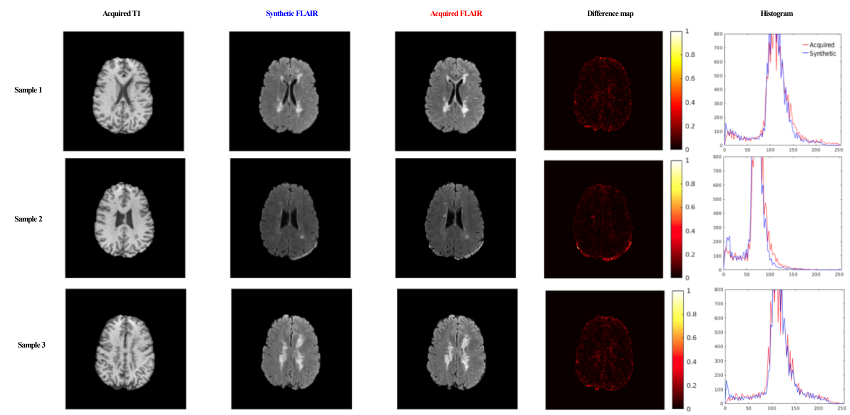

Figure 2. Synthesized 3D FLAIR 1x1x1 mm^3 images (**blue**) using acquired 3D T1 data alongside with acquired FLAIR (ground truth in **red**), difference map and matching histogram for the corresponding slice

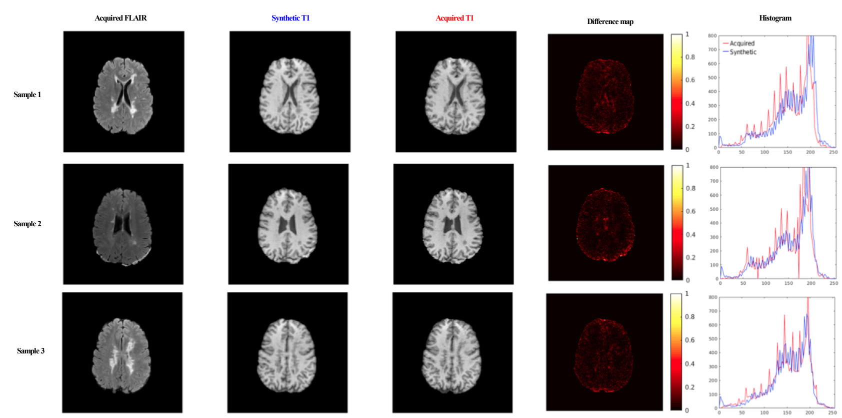

Figure 3. Synthesized 3D T1 1x1x1 mm^3 images (**blue**) using acquired 3D FLAIR data alongside with acquired 3D T1 (ground truth in **red**), difference map and matching histogram for the corresponding slice

RESULTS

63 additional MS cases with either 3D T1 or FLAIR images were used to validate the trained algorithm. **Figure 2** illustrates synthetic FLAIR images for a random slice from 3 different patients. Synthetic intensity histograms mostly match ground truth histograms and the difference map shows good match in normal appearing white/grey matter (NAWM/NAGM) while larger values are seen on the boundaries and around lesion edges. **Table 1** shows MAE, PSNR, MI and SSIM results calculated for each slice in each case. **Figure 3** shows similar results when FLAIR images are received as input and T1 is being synthesized.

Table 1. Quantitative comparison of synthesized images using four metrics commonly used in image processing applications

	Mean Absolute Error (MAE) Best = 0		Peak Signal to Noise Ratio (PSNR) 30 dB < Best < 50 dB		Mutual Information (MI) Best = 2		Structural Similarity Index (SSIM) Best = 1	
CASES	T1	FLAIR	T1	FLAIR	T1	FLAIR	T1	FLAIR
Sample 1	0.0128	0.0112	29.5493	30.0025	1.354	1.3265	0.9349	0.8867
Sample 2	0.0109	0.0084	29.3168	30.7040	1.3495	1.3221	0.9228	0.8524
Sample 3	0.0108	0.0100	30.3333	30.8356	1.3478	1.3320	0.9283	0.8891

CONCLUSION

Synthetic images may represent a breakthrough for quantitative analysis of heterogeneously acquired brain MS scans. Cycle-GAN shows excellent agreement in NAWM/NAGM against ground truth, while relaxing the condition to train with large paired datasets. The impact of these synthesized images as input in existing postprocessing pipelines (segmentation and volumetric algorithms) should now be investigated.

FUTURE WORKS

In addition to Cycle-GAN, other methods have been implemented or adapted for image synthesis and segmentation in our lab including Pix2pix with 3D kernels, SGAN, VAEGAN, UNIT and multiple input, multiple output GANs to inform the algorithm with more relevant information. Horizontal integration allows these models to be trained and optimized for several image processing applications and volumetric analysis.

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