An algorithm for creating the imitate 3D MRI/CT fusion images from the plain CT of lumbar spine using Generative Adversarial Networks

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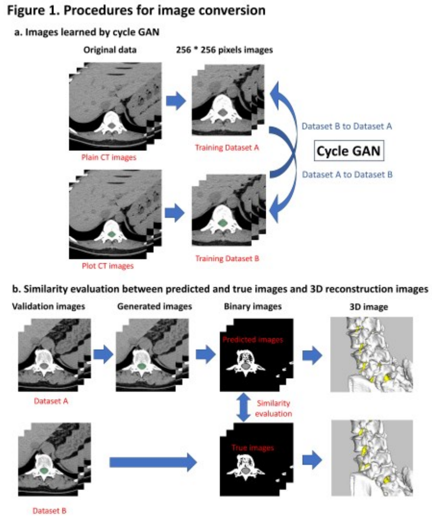
INTRODUCTION: Three-Dimensional Magnetic Resonance (MRI)/Computed Tomography (CT) fusion images are created through merging vertebrae reconstructed on the CT images with lumbar nerve roots derived from the 3D MR images. This technology is very useful not only for identifying the lumbar canal stenosis and compression of lumbar nerve roots, but also for preoperative planning for the surgery with transforaminal approaches such as full-endoscopic lumbar discectomy. However, 3D MRI/CT fusion imaging has some limitation, including that MRI images and CT images are required scanning with each specific equipment and subjects must keep the similar position during each scanning. The Cycle-consistent generative adversarial networks (Cycle GAN) can learn the relationship between two image datasets and translate the images in one dataset into similar images based on the other dataset. We hypothesized that it is possible for the Cycle GAN to generate the imitated 3D MRI/CT fusion images using plain CT images and the nerve plot CT images created from plain CT images. This study aims to develop an algorithm for generating the imitated 3D MRI/CT fusion images from plain CT images using Cycle GAN and validate the translated images.

METHODS: This study was conducted retrospectively. Data from 37 subjects who underwent the CT and MRI scanning at a single hospital from July 2021 to May2024 were included. Totally, 4246 plain CT images and 4295 plot CT images were obtained, which were converted from original Digital Imaging and COmmunications in Medicine (DICOM) files into Joint Photographic Experts Group (JPEG) files with dimensions of 256 × 256 pixels by cropping and resizing (Figure 1a). Among all images, 3154 plain CT images and 3203 plot CT images were used as training dataset A and training dataset B during Cycle GAN learning, and the other 1092 images each were validated using trained Cycle GAN model. The validation plain images had same field of view with validation plot images, where each plain image and plot image was paired. The validation images included data from three subjects, whose diagnosis were lumbar canal stenosis (LCS), Lumbar disc herniation (LDH) and no disease, respectively. Generated plot images and true plot images were transformed into binary images which demonstrate only bone regions and nerve regions with spinal canal and nerve roots (Figure 1b). To evaluate the accuracy of generated plot images, precision, recall, intersection over unit (IOU) and F1 score as the overlap indicators between generated plot images and true plot images, Structural SIMilarity (SSIM) and Peak Signal to Noise Ratio (PSNR) as the similarity indicators between generated and true images were calculated. Finally, the binary images of each subject were converted into each DICOM data using a specific code to add tag information of original DICOM data to the JPEG files. The computer was equipped with a central processing unit of Core i7-12700H (Intel), graphics processing unit of GeForce RTX 4090 (NVIDIA) and random-access memory of 32GB.

Figure 1. Procedures for image conversion



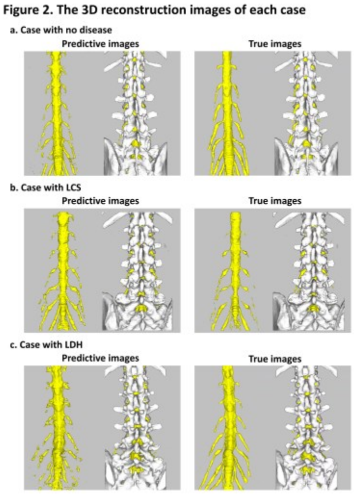
RESULTS: The cohort of 37 subjects consisted of 21 females and 16 males, with an average age of 48.8 ± 15.2 years. The diagnoses were as follows; LDH of 24, degenerative spondylolisthesis of 5, LCS of 4, spondylolysis of 2 and no disease of 2. In the validation of datasets with LCS, LDH and no disease, the overlap and similarity indicators between generated and true images were shown in Table 1. In verifying no disease case, the mean value of IOU for bone regions, IOU for nerve regions, SSIM, and PSNR were 0.82, 0.69, 0.90, and 17.4, respectively. The case with LCS had IOU for bone regions of 0.85, IOU for nerve regions of 0.64, SSIM of 0.90 and PSNR of 17.6, and the case with LDH had 0.90, 0.69, 0.89 and 18.3, respectively. It was possible to create the 3D reconstruction images utilizing binary images derived from three cases. The 3D reconstruction images of each case, which were created from generated plot images and true plot images, were illustrated in Figure 2.

Table 1. The overlap and similarity indicators between predictive and true images

Indicator	LCS		LDH		No disease	
	Vertebrae	Nerves	Vertebrae	Nerves	Vertebrae	Nerves
Precision	0.95	0.72	0.96	0.80	0.94	0.87
Recall	0.89	0.84	0.93	0.81	0.87	0.77
IOU	0.85	0.64	0.90	0.69	0.82	0.69
F1 score	0.92	0.77	0.95	0.80	0.90	0.81
SSIM	0.90		0.89		0.90	
PSNR	17.6		18.3		17.4	

LCS= lumbar canal stenosis, LDH= Lumbar disc herniation,
IOU= intersection over unit, SSIM= Structual SIMilarity, PSNR= Peak Signal to Noise Ratio

Figure 2. The 3D reconstruction images of each case



DISCUSSION: In present study, the mean IOUs of each ranged from 0.82 to 0.90 in bone regions and from 0.64 to 0.69 in nerve regions, indicating that trained Cycle-GAN model segmented the spinal canal and nerve roots with maintaining vertebrae structure because mean IOU of 0.5 usually is used as a cut-off value for acceptable level and mean IOU of 0.65 and 0.82 means discrepancies of approximately 11% and 5% between generated and true images. The mean value of SSIM and PSNR for binary images with vertebrae and nerve roots ranged from 0.89 to 0.90 and 17.4 to 18.3, which were relatively high similarity between generated and true images. These suggest that the imitated 3D MRI/CT fusion images, which were created from generated binary images, also had good accuracy. This technology is potentially innovative with further improvements in accuracy, because this algorithm can work with standard CT images in the general hospital without specific CT and MRI equipment.

SIGNIFICANCE: We developed an algorithm for creating the imitated 3D MRI/CT fusion images from plain CT images using Cycle GAN, and this algorithm is potentially innovative with further improvements in accuracy.