

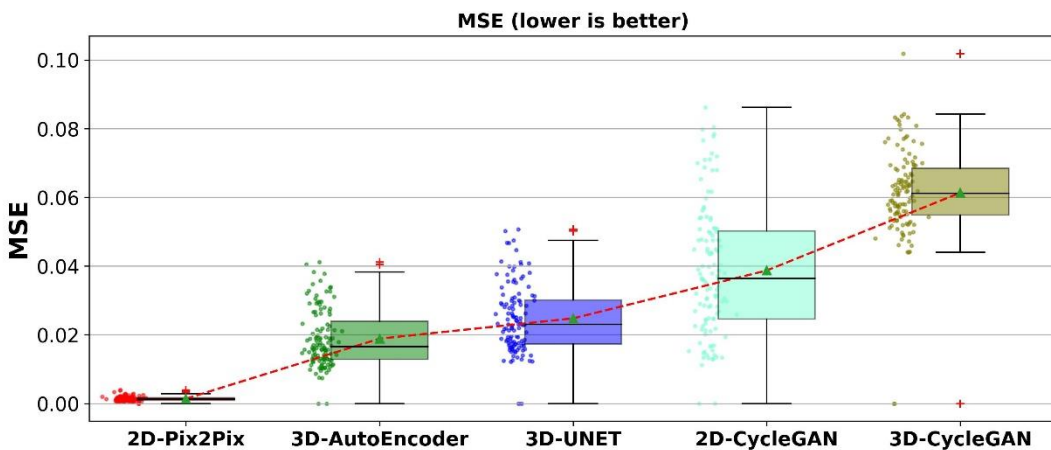
# Do High-Performance Image-to-Image Translation Networks Enable the Discovery of Radiomic Features? Application to MRI Synthesis from Ultrasound in Prostate Cancer

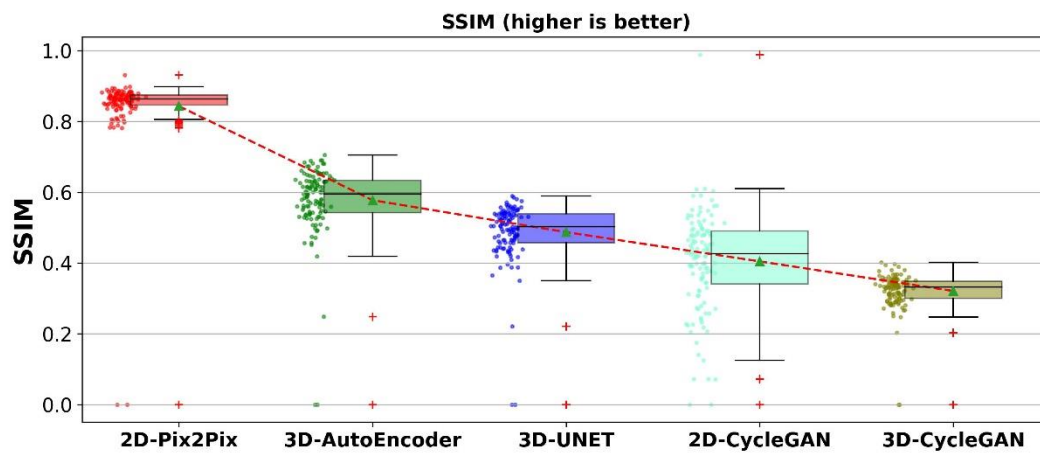
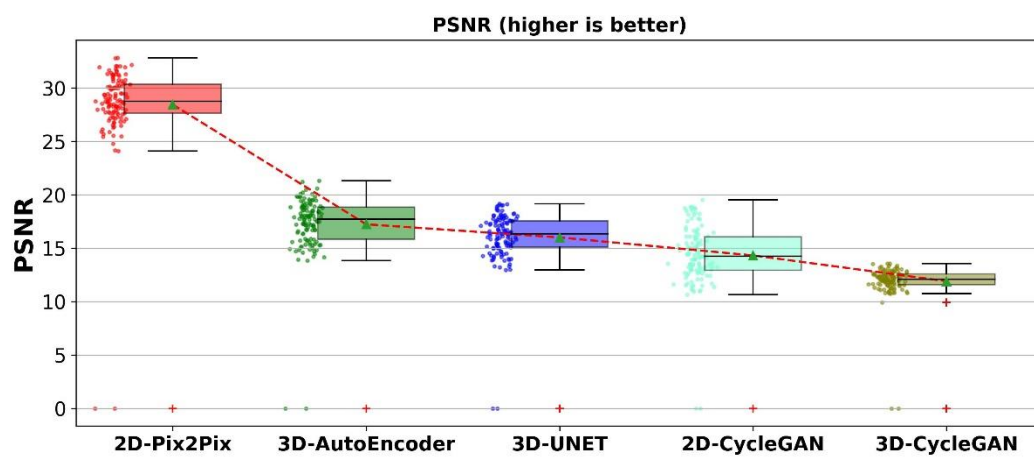
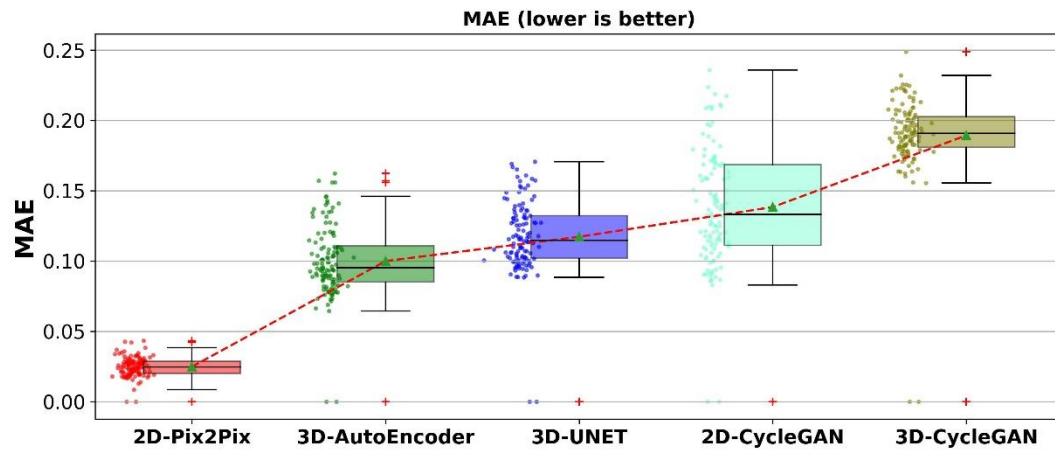
## High Resolution Figures and Tables

**Table.** Training parameters. D: Discriminator, G: Generator, MSE: Mean Squared Error, MAE: Mean Absolute Error, LSE: Least Squared Error.

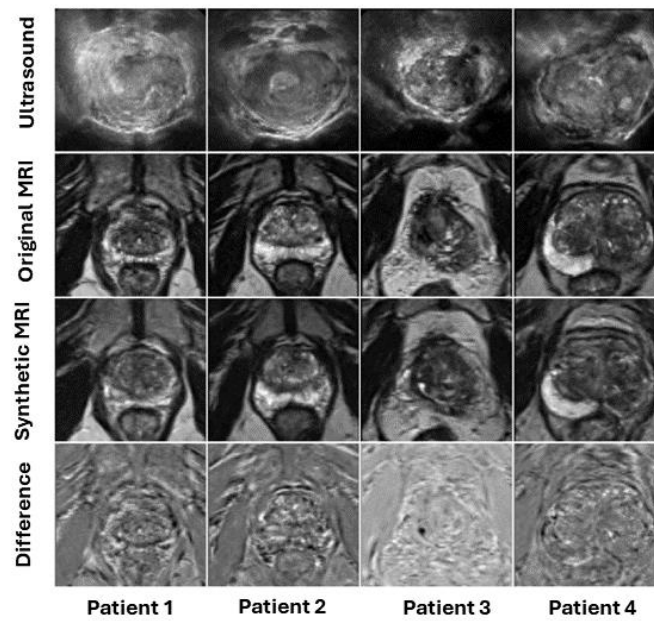
Parameters	2D-Pix2Pix	2D-CycleGAN	3D-CycleGAN	3D-AutoEncoder	3D-UNET
GPU	RTX 3090 24 GB	RTX 4090 24 GB	RTX 3090 24 GB	RTX 4090 24 GB	RTX 4090 24 GB
Framework	TensorFlow 2	TensorFlow 2	TensorFlow 2	TensorFlow 2	TensorFlow 2
Batch Size	1	1	1	1	1
Epoch	1000	1000	1000	1000	1000
Learning rate	D = 0.000001 G = 0.00001	D X = 0.0001 D Y = 0.0001 G G = 0.00001 G F = 0.00001	D = 0.000001 G = 0.0000001	0.00001	0.00001
Generative loss functions	L1 Loss (MAE)	Adversarial Loss (MSE) + Cycle Loss	Adversarial Loss (LSE) + Cycle Loss	MSE	MSE
Discriminator loss functions	Sigmoid Cross-Entropy Loss	Cycle-Consistency Loss	Cycle-Consistency Loss	MSE	MSE

**Figure.** A distribution of four quantitative evaluation metrics: MAE, MSE, SSIM, and PSNR for 2D-Pix2Pix, 2D-CycleGAN, 3D-CycleGAN, 3D-AutoEncoder, and 3D-UNET in synthesizing MRI images from Ultrasound images





**Figure.** four examples of synthetic MRI images provided by 2D-Pix2Pix. Rows show Ultrasound, Original MRI, Synthetic MRI, difference between original and synthetic MRI images. Columns show different patients. All synthetic images had SSIMs>0.85. MAE: Mean Absolute Error, MSE: Mean Square Error, SSIM: Structural Similarity Index, PSNR: Peak Signal to Noise Ratio.



i) Group 1

Feature Names	2D-CycleGAN	2D-Pix2Pix	3D-CycleGAN	3D-UNET	3D-AutoEncoder
GLRLM_rlnu_3d_avg	0.89	0.88	0.85	0.87	0.37
GLRLM_rlnu_3d_comb	0.89	0.88	0.85	0.87	0.36
NGTDM_coarseness_3D	0.87	0.87	0.80	0.88	0.88
GLRLM_glnu_3d_avg	0.84	0.86	0.71	0.80	0.82
GLRLM_glnu_3d_comb	0.84	0.86	0.71	0.80	0.82
NGLDM_dgnu_3D	0.87	0.84	0.84	0.83	0.85
NGLDM_glnu_3D	0.78	0.83	0.62	0.70	0.73
NGTDM_busyness_3D	0.82	0.82	0.75	0.81	0.75
NGTDM_strength_3D	0.78	0.79	0.75	0.69	0.61
GLDZM_id_var_3D	0.71	0.74	0.59	0.73	0.47
GLDZM_ide_3D	0.67	0.73	0.51	0.68	0.46
GLSZM_glnu_3D	0.71	0.69	0.57	0.67	-0.05
GLDZM_glnu_3D	0.71	0.69	0.57	0.67	-0.05
GLDZM_zdnu_norm_3D	0.58	0.66	0.25	0.54	0.20
GLDZM_sde_3D	0.57	0.64	0.22	0.53	0.21
IS_energy	0.55	0.55	0.58	0.54	0.53
GLDZM_zd_entr_3D	0.53	0.54	0.24	0.51	0.15
GLSZM_zsnu_3D	0.56	0.53	0.40	0.49	-0.09

ii) Group 2

Feature Names	2D-CycleGAN	2D-Pix2Pix	3D-CycleGAN	3D-UNET	3D-AutoEncoder
GLCM_info_corr2_3d_comb	-0.14	0.77	-0.25	-0.09	0.00
NGLDM_dc_energy_3D	-0.10	0.76	-0.11	-0.03	0.10
GLCM_info_corr2_3d_avg	-0.13	0.76	-0.25	-0.09	-0.01
NGLDM_dc_entr_3D	-0.04	0.74	-0.10	-0.06	0.09
IH_min_grad	0.53	0.73	0.36	0.50	0.47
IS_qcod	0.17	0.73	-0.21	-0.15	-0.11
GLRLM_rl_entr_3d_avg	-0.05	0.73	-0.10	-0.10	-0.01
GLCM_corr_3d_avg	0.11	0.72	-0.16	-0.06	-0.01
GLRLM_rl_entr_3d_comb	-0.04	0.72	-0.11	-0.11	-0.02
GLCM_corr_3d_comb	0.10	0.72	-0.16	-0.06	-0.01
IH_kurt	0.06	0.71	-0.04	-0.09	0.02
IS_kurt	0.07	0.70	-0.04	-0.08	0.03
IH_cov	0.15	0.70	0.03	-0.14	0.14
IS_cov	0.21	0.69	-0.05	-0.08	0.02
IH_max_grad	0.55	0.68	0.41	0.44	0.54
IH_rmad	-0.03	0.67	-0.16	-0.13	-0.01
IS_skew	-0.06	0.65	0.04	0.02	0.22
IH_skew	-0.06	0.65	0.04	0.01	0.22
IH_uniformity	-0.12	0.64	-0.16	-0.21	0.02
NGLDM_lhge_norm_3D	-0.12	0.64	-0.16	-0.21	0.02
GLSZM_lhge_3D	0.51	0.64	0.29	0.43	0.48
NGLDM_hdhege_3D	0.26	0.64	0.16	-0.09	0.17
IH_mad	0.10	0.64	-0.15	-0.17	-0.05
IH_medad	0.07	0.64	-0.15	-0.18	-0.03
IH_lqr	0.03	0.63	-0.18	-0.22	0.00
GLRLM_glnu_norm_3d_avg	-0.10	0.63	-0.13	-0.20	0.02
GLRLM_glnu_norm_3d_comb	-0.10	0.62	-0.13	-0.20	0.02
GLCM_sum_entr_3d_comb	-0.06	0.61	-0.12	-0.22	0.01
GLCM_sum_entr_3d_avg	-0.05	0.61	-0.12	-0.22	0.01
GLCM_sum_var_3d_avg	0.10	0.61	-0.12	-0.17	-0.03
GLCM_clust_tend_3d_avg	0.10	0.61	-0.12	-0.17	-0.03
GLCM_sum_var_3d_comb	0.10	0.61	-0.12	-0.17	-0.04
GLCM_clust_tend_3d_comb	0.10	0.61	-0.12	-0.17	-0.04
GLDZM_zdnu_3D	0.43	0.59	0.27	0.26	-0.02
IH_entropy	-0.07	0.59	-0.11	-0.23	0.01
IH_qcod	0.04	0.59	-0.17	-0.20	-0.06
GLDZM_sdhege_3D	0.34	0.59	0.29	0.12	0.31
GLCM_joint_var_3d_avg	0.10	0.59	-0.12	-0.16	-0.04
GLCM_joint_var_3d_comb	0.10	0.58	-0.12	-0.16	-0.04
IH_p90	0.03	0.58	0.05	-0.14	0.01
IH_var	0.08	0.58	-0.13	-0.17	-0.05
NGLDM_gl_var_3D	0.08	0.58	-0.13	-0.17	-0.05
GLSZM_zs_var_3D	0.37	0.56	0.30	0.31	0.38
GLSZM_lse_3D	0.37	0.56	0.30	0.31	0.37
IH_median	0.10	0.55	0.01	-0.12	0.11
GLCM_energy_3d_avg	-0.03	0.55	-0.01	-0.09	-0.05
GLRLM_gl_var_3d_comb	0.08	0.55	-0.09	-0.15	-0.04
GLCM_auto_corr_3d_avg	0.19	0.55	0.05	-0.16	0.08
GLCM_auto_corr_3d_comb	0.19	0.55	0.05	-0.16	0.08
GLRLM_gl_var_3d_avg	0.09	0.55	-0.09	-0.15	-0.04
GLRLM_lrhge_3d_avg	0.13	0.55	0.07	-0.17	0.21
GLRLM_lrhge_3d_comb	0.16	0.55	0.07	-0.17	0.20
GLCM_energy_3d_comb	-0.04	0.55	-0.01	-0.09	-0.05
NGLDM_hge_3D	0.19	0.54	0.05	-0.16	0.08
GLCM_joint_avg_3d_comb	0.21	0.53	0.06	-0.15	0.09
GLCM_sum_avg_3d_comb	0.21	0.53	0.06	-0.15	0.09
GLRLM_hgre_3d_comb	0.19	0.53	0.04	-0.15	0.07
GLRLM_hgre_3d_avg	0.19	0.53	0.05	-0.15	0.08
GLCM_joint_avg_3d_avg	0.21	0.53	0.06	-0.15	0.09
GLCM_sum_avg_3d_avg	0.21	0.53	0.06	-0.15	0.09
IH_mean	0.20	0.53	0.06	-0.15	0.09
IVH_auc	0.20	0.53	0.06	-0.15	0.09
GLRLM_srhege_3d_comb	0.19	0.52	0.03	-0.14	0.05
GLRLM_srhege_3d_avg	0.20	0.52	0.03	-0.14	0.04
NGTDM_contrast_3D	0.12	0.52	-0.12	-0.12	-0.06
GLCM_info_corr1_3d_comb	-0.14	0.51	-0.16	0.03	-0.32
GLDZM_ldhege_3D	0.45	0.51	0.22	0.31	0.11
IH_min_grad_g	0.00	0.50	-0.02	-0.09	0.11
GLCM_joint_max_3d_comb	-0.10	0.50	0.10	-0.10	-0.13
GLCM_joint_entr_3d_comb	0.04	0.50	-0.03	-0.09	-0.07
GLCM_joint_entr_3d_avg	0.05	0.50	-0.03	-0.09	-0.07
IS_p10	-0.18	0.50	-0.11	-0.05	0.01
IVH_i90	-0.18	0.50	-0.11	-0.05	0.01
GLCM_info_corr1_3d_avg	-0.17	0.50	-0.16	0.03	-0.33
GLCM_joint_max_3d_avg	-0.10	0.50	0.10	-0.10	-0.13

iii) Group 3

Feature Names	2D-CycleGAN	2D-Pix2Pix	3D-CycleGAN	3D-UNET	3D-AutoEncoder
GLSZM_lzige_3D	0.27	0.46	0.21	0.12	0.21
IH_max_grad_g	0.12	0.45	0.04	-0.21	-0.12
IS_rmad	0.02	0.44	-0.02	0.01	-0.09
GLCM_clust_shade_3d_comb	0.03	0.43	0.02	0.12	-0.07
GLCM_clust_shade_3d_avg	0.03	0.43	0.02	0.12	-0.07
IS_lqr	-0.02	0.43	-0.03	-0.01	-0.09
IVH_v10	0.09	0.43	0.21	-0.15	0.16
GLCM_clust_prom_3d_avg	0.04	0.42	-0.02	-0.12	-0.05
NGLDM_lgce_3D	0.13	0.42	0.07	-0.22	0.10
GLCM_clust_prom_3d_comb	0.04	0.42	-0.02	-0.12	-0.05
GLRLM_srige_3d_avg	0.14	0.41	0.11	-0.21	0.16
GLRLM_lgre_3d_comb	0.14	0.41	0.08	-0.20	0.10
GLRLM_srige_3d_comb	0.14	0.41	0.11	-0.21	0.16
GLRLM_lgre_3d_avg	0.14	0.41	0.08	-0.21	0.10
IH_mode	-0.01	0.41	-0.12	-0.15	-0.03
IH_p10	0.07	0.41	0.05	-0.20	0.08
GLRLM_rlnu_norm_3d_comb	-0.01	0.40	0.04	0.06	-0.10
GLRLM_sre_3d_comb	-0.02	0.40	0.04	0.06	-0.10
NGLDM_hde_3D	0.02	0.39	0.14	0.05	-0.12
GLRLM_sre_3d_avg	0.00	0.39	0.04	0.06	-0.09
NGLDM_dgnu_norm_3D	-0.01	0.39	0.18	0.04	-0.21
GLRLM_rlnu_norm_3d_avg	-0.01	0.39	0.04	0.06	-0.10
GLRLM_r_perc_3d_avg	0.02	0.39	0.10	0.05	-0.11
GLRLM_r_perc_3d_comb	0.02	0.39	0.10	0.05	-0.11
GLCM_inv_diff_norm_3d_comb	-0.04	0.38	-0.03	0.06	-0.14
GLCM_inv_diff_norm_3d_avg	-0.03	0.38	-0.03	0.06	-0.14
NGLDM_dc_var_3D	0.02	0.38	0.26	0.05	-0.26
NGLDM_hdige_3D	0.10	0.38	-0.03	-0.13	0.00
IVH_diff_i10_i90	0.09	0.38	0.03	0.01	-0.05
GLCM_inv_diff_mom_3d_avg	-0.01	0.38	0.04	0.06	-0.13
GLCM_inv_diff_3d_avg	-0.02	0.38	0.04	0.06	-0.13
GLCM_diff_avg_3d_avg	-0.03	0.38	-0.04	0.06	-0.14
GLCM_dissimilarity_3d_avg	-0.03	0.38	-0.04	0.06	-0.14
GLCM_diff_avg_3d_comb	-0.03	0.37	-0.04	0.06	-0.15
GLCM_dissimilarity_3d_comb	-0.03	0.37	-0.04	0.06	-0.15
IS_median	0.11	0.37	0.01	-0.10	-0.06
GLCM_inv_diff_mom_3d_comb	-0.02	0.37	0.04	0.06	-0.13
GLRLM_rl_var_3d_comb	0.04	0.37	0.18	0.05	-0.13
GLCM_inv_var_3d_avg	0.06	0.37	-0.13	0.02	0.17
GLCM_inv_var_3d_comb	0.06	0.37	-0.13	0.01	0.17
GLCM_inv_diff_3d_comb	-0.01	0.37	0.04	0.06	-0.13
GLRLM_lre_3d_comb	0.03	0.37	0.15	0.05	-0.12
GLRLM_rl_var_3d_avg	0.03	0.37	0.18	0.05	-0.13
GLRLM_lre_3d_avg	0.03	0.37	0.15	0.04	-0.12
IS_medad	0.07	0.36	0.01	0.04	-0.05
IS_mad	0.07	0.36	0.01	0.06	-0.04
GLRLM_lrhge_3d_comb	0.07	0.36	0.00	-0.15	0.01
GLRLM_lrhge_3d_avg	0.01	0.36	0.00	-0.15	0.01
IVH_diff_v10_v90	0.06	0.35	0.03	-0.12	0.15
NGLDM_lidige_3D	0.26	0.35	0.23	-0.15	0.27
IS_mean	0.11	0.34	0.00	0.02	-0.06
IS_p90	0.09	0.34	0.03	0.08	-0.11
IVH_i10	0.09	0.34	0.03	0.08	-0.11
GLDZM_lidige_3D	0.21	0.33	0.20	0.16	0.26
GLCM_diff_entr_3d_comb	-0.03	0.32	-0.07	0.05	-0.14
GLCM_inv_diff_mom_norm_3d_avg	-0.01	0.32	-0.09	0.04	-0.14
GLCM_inv_diff_mom_norm_3d_comb	-0.01	0.32	-0.09	0.04	-0.14
GLCM_contrast_3d_avg	0.00	0.32	-0.09	0.04	-0.14
NGLDM_lde_3D	0.04	0.32	-0.04	0.05	-0.05
GLCM_contrast_3d_comb	0.00	0.32	-0.09	0.04	-0.14
IS_rms	0.10	0.31	0.02	0.02	-0.07
GLCM_diff_entr_3d_avg	-0.02	0.31	-0.07	0.05	-0.14
NGLDM_lidhege_3D	0.10	0.30	-0.06	-0.08	-0.02
IJ_peak_loc	0.03	0.28	0.04	0.17	0.01
IJ_peak_glob	0.10	0.28	0.01	0.22	0.17
IS_var	0.08	0.27	0.05	0.09	0.02
GLCM_diff_var_3d_avg	0.04	0.27	-0.10	0.02	-0.13
GLCM_diff_var_3d_comb	0.05	0.27	-0.10	0.02	-0.13
GLSZM_z_perc_3D	0.04	0.25	-0.06	0.03	-0.02
GLDZM_z_perc_3D	0.04	0.25	-0.06	0.03	-0.02
GLSZM_lgze_3D	0.28	0.24	0.17	-0.19	0.05
GLDZM_lgze_3D	0.28	0.24	0.17	-0.19	0.05
GLSZM_szlige_3D	0.26	0.23	0.19	-0.17	-0.10
GLDZM_szlige_3D	0.16	0.22	0.16	-0.07	0.01
GLSZM_zs_entr_3D	0.22	0.21	0.11	0.11	0.11
GLSZM_hgre_3D	0.08	0.21	-0.03	-0.17	0.03
GLDZM_hgre_3D	0.08	0.21	-0.03	-0.17	0.03
NGTDM_complexity_3D	0.05	0.19	-0.11	0.09	-0.10
GLSZM_szhege_3D	0.04	0.14	-0.03	-0.17	0.03
GLSZM_glnu_norm_3D	0.00	0.14	0.14	-0.02	-0.01
GLDZM_glnu_norm_3D	0.00	0.14	0.14	-0.02	-0.01
GLSZM_gl_var_3D	-0.02	0.13	0.20	0.00	-0.10
GLDZM_gl_var_3D	-0.02	0.13	0.20	0.00	-0.10
IS_max	0.00	0.11	-0.04	0.25	0.12
IS_min	-0.09	0.10	0.01	-0.03	0.20
IS_range	0.09	0.09	-0.03	0.29	0.18
IVH_v90	-0.07	0.07	-0.06	-0.04	-0.04
GLSZM_zsnu_norm_3D	0.02	0.06	-0.08	-0.07	0.08
GLSZM_sze_3D	0.02	0.06	-0.08	-0.07	0.07
IH_min	0.00	0.00	0.00	0.00	0.00
IH_max	0.00	0.00	0.00	0.00	0.00
IH_range	0.00	0.00	0.00	0.00	0.00
NGLDM_dc_perc_3D	0.00	0.00	0.00	0.00	0.00

**Figure.** Different Radiomic feature (RF) groups provided by RF Analysis. i) Group 1 showed 18 low-level RFs successfully discovered by synthetic MRI images generated through majority of algorithms, ii) Group 2 showed 75 low-level RFs were successfully discovered from synthetic MRI images generated by 2D-Pix2Pix, and iii) Group 3 showed synthetic MRI images generated by the current generative networks couldn't discovered 93 low-level RFs.

**Table.** Qualitative analysis of synthetic MRI by 5 medical doctors (D).

Questions (Q), Scoring system: 0= zero, 1= low, 2=intermediate, 3=high, 4=very high	D 1	D 2	D 3	D 4	D 5
Q1: What is your medical specialty and how many years of experience do you have in interpreting MRI and ultrasound images? (years)	>5	>6	>5	>5	>5
Q2: How many doctors could discriminate the synthetic MRI from the original MRI properly? (15 external testing images existed)	15	15	15	15	15
Q3: After specifying synthetic and original MRI for you, how would you rate the overall quality of synthetic MRI images compared to original MRI?	1	2	1	1	1
Q4: Are there any noticeable artifacts or inaccuracies in the synthetic MRI images?	4	2	4	4	3
Q5: How confident are you in making a diagnosis based on synthetic MRI images versus original MRI?	1	1	1	1	1
Q6: Do synthetic MRI images offer any additional diagnostic information compared to the original MRI images? How much?	0	0	0	0	0
Q7: Do synthetic MRI images offer any additional diagnostic information compared to the original Ultrasound images? How much?	2	2	3	2	3
Q8: How do you assess the resolution and contrast of the synthetic MRI images, compared to original MRI images?	1	2	1	2	2
Q9: In your opinion, how much are the potential clinical benefits of using synthetic MRI images?	4	3	3	4	3
Q10: Would you support the integration of synthetic MRI technology into regular clinical practice? How much?	4	4	4	4	4