Fully automatic detection and quantification of new white matter lesions using deep learning

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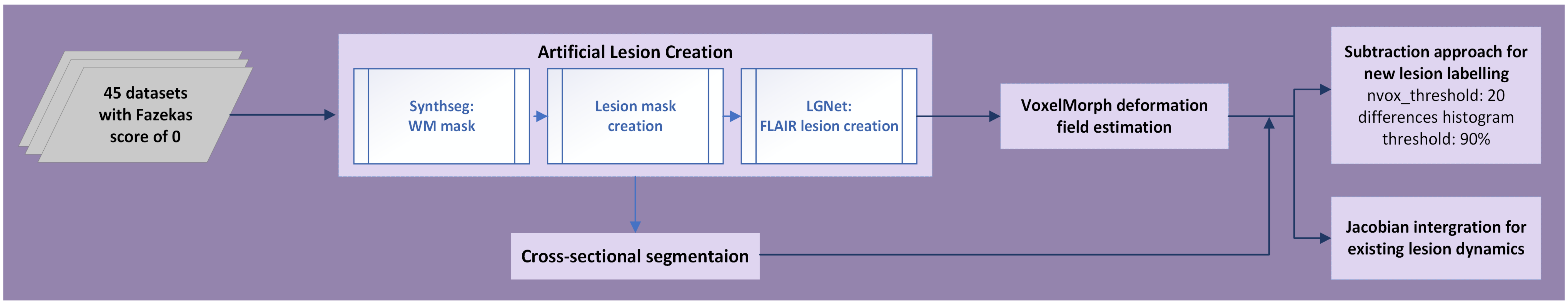
Accurate detection, segmentation, and quantification of lesion dynamics in longitudinal MRI is crucial for monitoring disease progression in Multiple Sclerosis, and for evaluating the efficacy of therapeutic interventions. **We present an efficient, automatic method utilising deep learning to assess lesion changes in FLAIR MRI with a high degree of accuracy.**

Our new methodology performs well in identifying new lesions in a simulated dataset, is sensitive to lesion dynamics, and outperforms simpler methods of subtracting cross-sectionally derived lesion volumes.



We retrained VoxelMorph[2], a **deep learning model which estimates deformation flow fields** between image pairs, on 200 FLAIR image pairs from ADNI [3] with interscan intervals between 1 and 3 years. This model was used to estimate the deformation fields between the follow-up (FU) and baseline (BL) images.

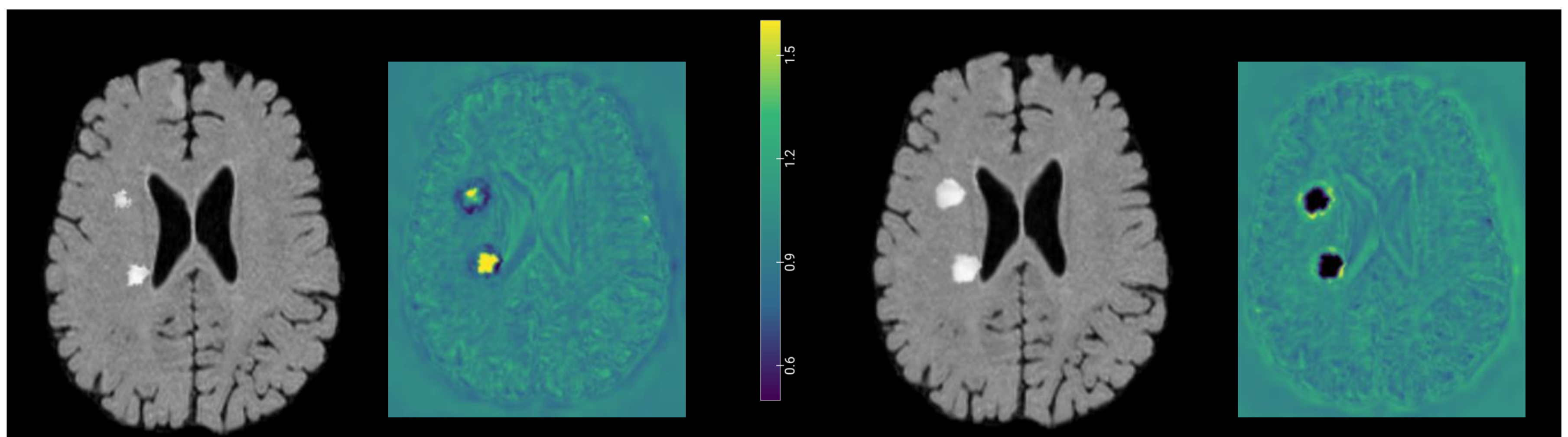


Fig. 1. Left: BL image and Jacobian determinant showing high intensity for lesion that grew from BL to FL. Right: FU image and Jacobian determinant image showing lesion that shrinks toward original image

The Jacobian determinant of the flow field represents the voxel-wise change between images, with values >1 representing expansion and values <1 shrinkage. **By integrating the Jacobian within lesion masks, we can estimate measures of lesion volume change between the image pairs.** The images in Fig. 1 show how the Jacobian's are mostly ~1 except in the lesions, which expanded from BL to FU.

We show a strong correlation (r = 0.96, Fig 4a) between the **per-lesion ground truth percentage volume change and the estimated volume change** by the Jacobian methodology within the simulated lesion masks. This reduced marginally to r = 0.95 when computing volume change with the Jacobian method applied within the cross-sectional lesion segmentations generated by our white matter hyperintensity segmentation pipeline. The correlation between the percentage change derived solely from differences in cross-sectional lesion masks between timepoints was notably poorer (r = 0.73, Fig 4b).

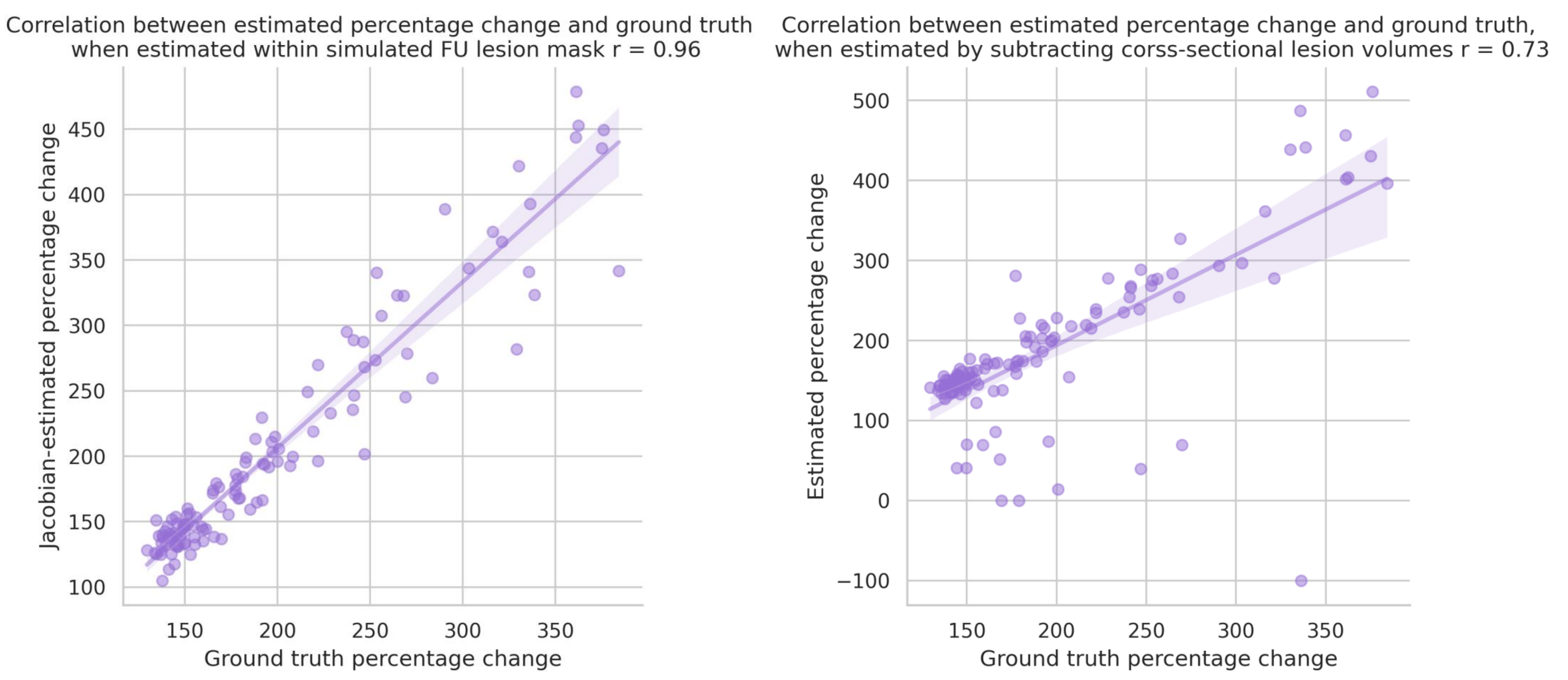


Fig. 4: Correlations between ground truth percentage change and a) our new methodology, b) traditional methodology

We retrained LG-Net [1], a deep learning algorithm for T1W lesion inpainting**, to artificially generate new and expanding lesions** for 45 FLAIR images. We simulated between 1 and 5 new lesions per dataset, with each lesion ranging between 50mm^3 and 500mm^3.

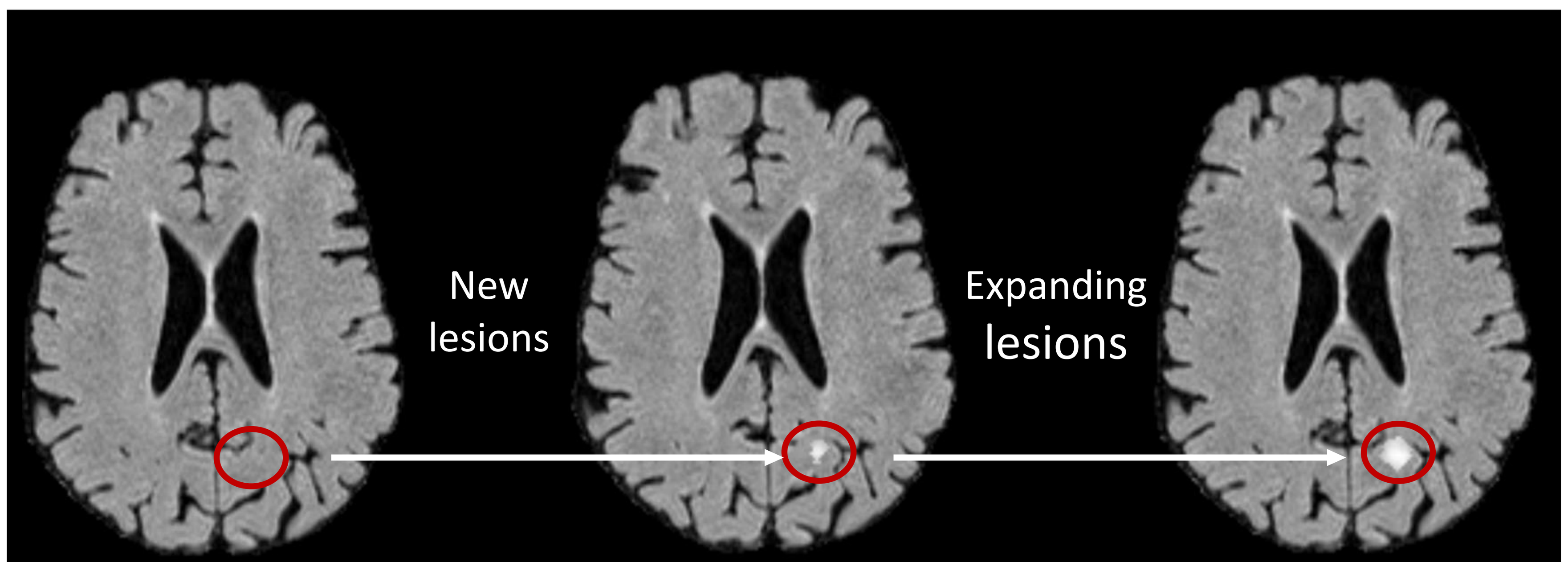


Fig. 2: Examples of artificial new and expanding lesions

New lesions were labelled based on a difference image (Fig 3a) of the FU image, transformed with the VoxelMorph flow field, and the BL image. Lesions existing in both images could be warped successfully, however lesions present in only the FU reported clear differences after transformation. By thresholding (Fig 3b) the difference image we were able to label new lesions present only in the FU timepoint.

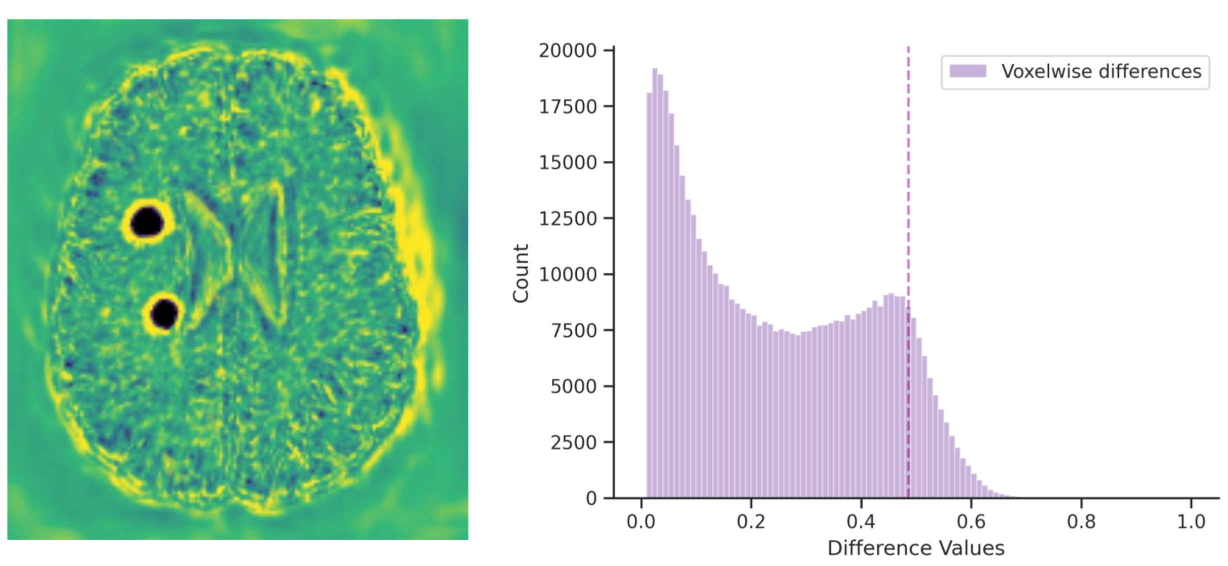
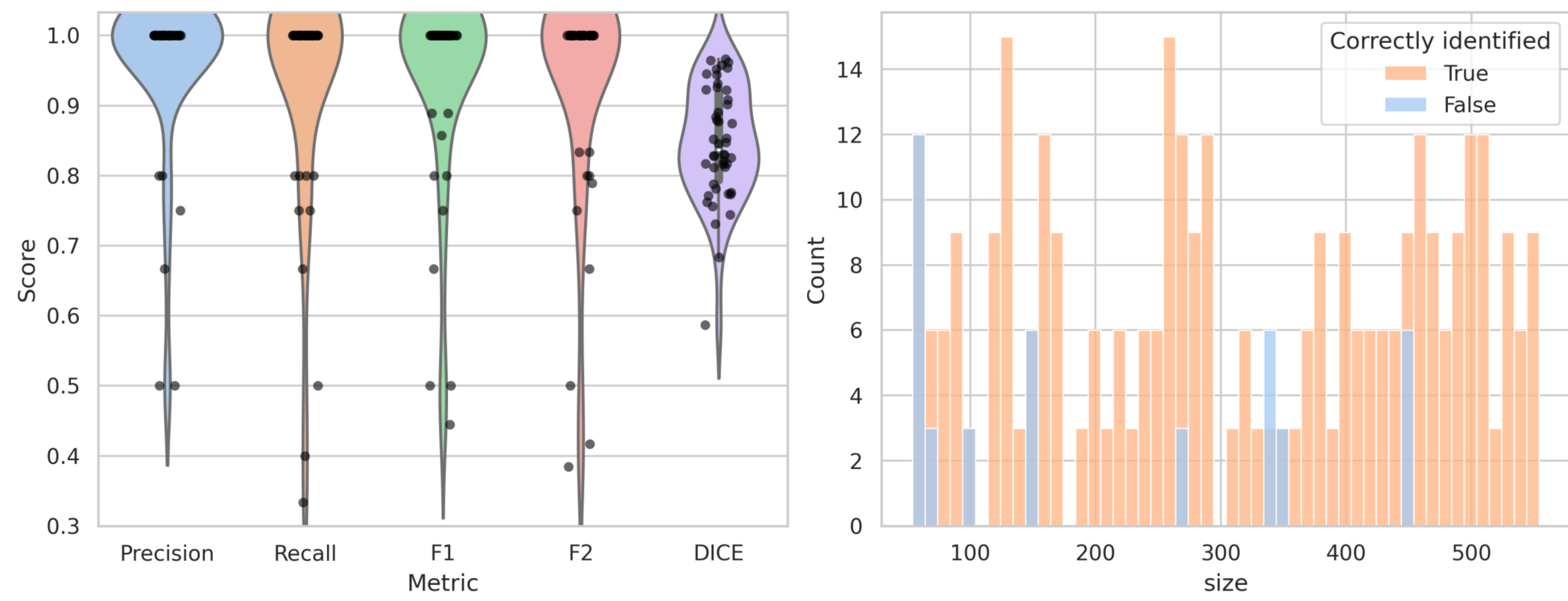


Fig. 3: a) Subtraction image; b) Histogram of voxelwise differences and 90% percentile

New lesions identified by the pipeline were considered a true positive if they overlapped >50% with the ground truth lesion mask. **The method showed excellent performance and successfully identified new lesions across a range of lesion sizes.**

Precision (mean)	Recall (mean)	F1 (mean)	F2 (mean)	DICE (mean)
0.95	0.92	0.94	0.93	0.85



[1] VoxelMorph: A Learning Framework for Deformable Medical Image Registration Guha Balakrishnan, Amy Zhao, Mert R. Sabuncu, John Guttag, Adrian V. Dalca IEEE TMI: Transactions on Medical Imaging. eprint arXiv:1809.05231 *2019*

[2] LG-Net: Lesion Gate Network for Multiple Sclerosis Lesion Inpainting Zihao Tang et al Medical Image Computing and Computer Assisted Intervention – MICCAI 2021, *2021*

[3] Alzheimer's Disease Neuroimaging Initiative http://adni.loni.usc.edu