Deep Learning and Bayesian Inference System for Automated Brain MR Diagnosis Performs at Level of Academic Neuroradiologists and Augments Resident Performance

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Introduction
As both the complexity and volume of medical imaging increases, there is a pressing need for automated quantitative and probabilistic image analyses that can improve the efficiency and accuracy of the radiology workflow. We leveraged advanced image processing methods, convolutional neural networks and subspecialty expertise encapsulated within Bayesian networks to create an automated system to quantitatively characterize multimodal brain MRIs and automatically generate a probabilistic differential diagnosis for 35 disease entities involving deep gray matter.

Hypothesis
We hypothesized that such an automated system would perform at the level of an academic neuroradiologist in a set of held-out validation cases. Additionally, we hypothesized that results from the system, when displayed through an interactive clinical decision support tool, could bring the performance of a resident to the level of a subspecialty trained academic neuroradiologist.

Methods
390 clinically-validated cases were split into training (n = 288) and validation (n = 102) samples. Seven clinical MR modalities (T1W, T2W, FLAIR, T1post, GRE, DWI/ADC) were incorporated into a customized image-processing pipeline (Figure 1A) using ANTs tissue segmentations and customized 3D U-Net convolutional neural networks (Figure B), for abnormal signal detection for each MR sequence (FLAIR, T1, GRE; Figure 1C). Restricted diffusion, enhancement and T2 signal were detected with separate image processing techniques.
Abnormal signal features and spatial and anatomic subregion features derived from an atlas-based image processing pipeline were combined with clinical information (age, gender, chronicity, immune status) in an expert-trained naïve Bayes network focused on 35 diagnoses known to involve deep gray matter (Figure 2A). Within the validation sample, the performance of the fully automated system was compared to radiology residents, neuroradiology fellows, community radiologists and academic neuroradiology attendings. A subset of radiology residents used our in-house Adaptive Radiology Interpretation & Education System (ARIES; Figure 2B) to review and interact with the results of the automated pipeline for half of the validation cases.

**Results**

The image-processing and feature-extraction pipelines were 90% accurate compared to attending-extracted ground truth features. The fully automated pipeline, integrating imaging and clinical features, determined an accurate differential diagnosis in 84% of the cases (top 3; Figure 3A) and the exact diagnosis in 63% of the cases, which was significantly better than residents (55%/36%), community radiology attendings (52%/33%), neuroradiology fellows (72%/59%), and comparable to academic neuroradiology attendings (84%/67%). The residents that used ARIES for decision support performed at the level of academic neuroradiologists (87%/66%; Figure 3B).
Figure 3. A) Overall diagnostic performance of automated methods pipeline compared to radiologists at different experience levels. B) Comparison of resident performance with and without interacting with automated pipeline results in ARIES.

Conclusion
We developed a system for automated diagnosis that computationally mirrors the two fundamental steps to image interpretation by combining convolutional neural networks, image processing, and Bayesian networks. It performs at the level of an academic neuroradiologist in diagnosing complex brain MRI’s for 35 disease entities. Furthermore, we demonstrate that ARIES, an interactive clinical decision support tool, can augment the performance of radiology residents to the level of academic neuroradiologists.

Statement of Impact
This sort of AI-based clinical decision support system has the potential to significantly improve the accuracy and efficiency of the radiology workflow by automatically generating quantitative imaging features and providing differential diagnoses at the level of subspecialty academic neuroradiology attendings.

Keywords
deep learning, convolutional neural networks, neuroradiology, brain MRI, U-Net, artificial intelligence, Bayesian inference, clinical decision support