S3 Detecting Parkinson's: DTI vs. fMRI

Objectives:

- Demonstrate an understanding of DTI and fMRI.
- Compare the advantages and disadvantages of DTI and fMRI in Parkinson's disease diagnosis.

Thesis:

DTI and fMRI improve the early detection and diagnosis of Parkinson's disease in the beginning or early stages, allowing for timely interventions.

Definitions:

Parkinson's Disease (PD): Parkinson's is a neurodegenerative disease from a lack of dopamine that affects motor stability. PD can cause symptoms like tremors and stiffness. PD can also have non-motor effects, such as memory problems and depression, which can greatly affect their quality of life. Early detection of PD is extremely important as it leaves more time for trials and lifestyle changes (Cattaneo and Jost, 2023).

Diffusion Tensor Imaging (DTI) definition:
Evaluates the magnitude and directionality of water diffusion within the tissue. This helps show structures and conditions of the white matter in the brain and its connections.
DTI looks at fractional anisotropy (FA), which shows how much water is restricted in one direction. Having a high FA means that the water moves in one direction, indicating healthy white matter or no signs of early PD (Zhang, 2020).

Functional MRI (fMRI) definition:
fMRI is an imaging method that measures brain activity and patterns. This allows researchers and physicians to observe specific regions of the brain during tasks, behaviors, and thoughts in real time through neural function tracking—for example, tremors associated with PD (Barreiros, 2024).

DTI:

Early-Stage PD

- Shows lower fractional anisotropy (FA) in the posterior portions of the substantia nigra, resulting in deterioration of white matter, allowing for free water, which shows changes in motor functions related to PD (Mitchell et al., 2021).

Moderate to late-stage PD

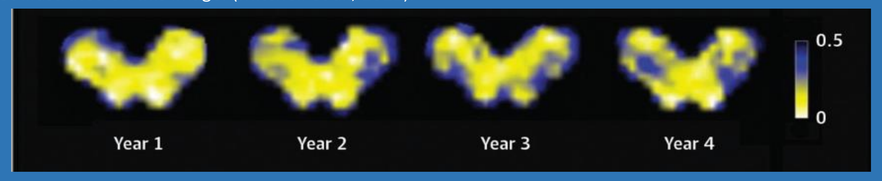
- Posterior and anterior damage to the substantia nigra, indicating more damage to white matter (Mitchell et al., 2021).
- The nucleus basalis of Meynert (group of neurons) shows water diffusion abnormalities, which indicate cognitive, attentive, and arousal decline related to PD (Mitchell et al., 2021).

DTI Disadvantages:

- There are overlapping pathologies that can make it challenging for DTI to interpret.
- DTI is very complex, so it is not used widely yet.
- DTI can be utilized on several MRI scanners and set differently in each scenario, which may produce varying results (Chouliaras, 2023).

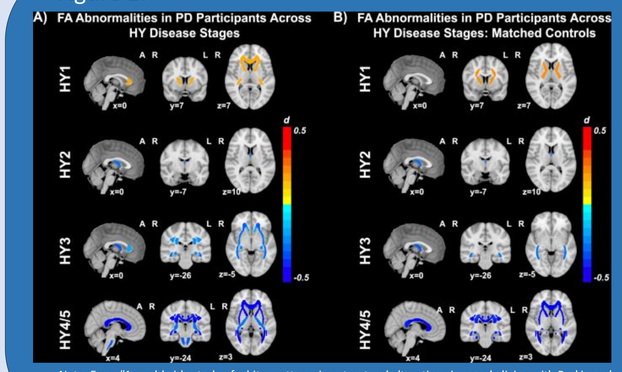
Figure 1: Cell Deterioration in the Brain on DTI Scan.

This figure shows changes in the brain of the person with early Parkinson's over four years. The yellow areas represent higher levels of free water in the substantia nigra, which indicates brain cell deterioration. The blue areas show lower free water levels, meaning healthier tissues. Even though there looks like there are more blue areas in later years, that is due to other brain regions adapting but not necessarily improving, and other areas of the brain being damaged, which are not illustrated on this image. (Mitchell et al., 2021).



Note. From "Emerging Neuroimaging Biomarkers Across Disease Stage in Parkinson Disease: A Review," by Mitchell T, Lehéricy S, Chiu SY, Strafella AP, Stoessl AJ, Vaillancourt DE, *JAMA Neurology*, *78*(10), 1262–1272. (https://doi.org/10.1001/jamaneurol.2021.1312). Copyright 2025 by Elsevier. Reprinted with permission.

Figure 2:



White matter in the brain becomes progressively damaged in people with Parkinson's. The colored areas show changes in FA and the measurement of white matter. In the early stages (HY1), the orange areas show a minor increase in FA that can indicate early compensatory changes. As the disease progresses (HY2-Hy4/5), blue areas appear and start to spread, which indicates FA and worsening white matter damage. This shows how DTI can show a gradual loss of brain connectivity as PD progresses (Owens-Walton et al., 2024).

Note. From "A worldwide study of white matter microstructural alterations in people living with Parkinson's disease," by C., Dirkx, M. F., Druzgal, J., Emsley, H. C. A., Guimarães, R., Haroon, H. A., Helmich, R. C., Hu, M. T., Johansson, M. E., Kim, H. B., ... van der Werf, Y., *NPJ Parkinson's disease*, *10*(1), 151. (https://doi.org/10.1038/s41531-024-00758-3). Copyright 2025 by Elsevier. Reprinted with permission.

fMRI:

- fMRI tracks any changes in blood oxygen levels in the brain to show which regions are active. The motor and cognitive brain functions with fMRI evaluate PD and detect early roadblocks and any other issues in the brain (Chouliares and O'Brien, 2023).
- fMRI is extremely useful for detecting abnormalities in the brain's functional networks that can be affected by PD. fMRI allows for precise brain mapping of function. It demonstrates how different areas of the brain communicate and function together, highlighting disruptions caused by PD (Bidesi et al., 2021).
- Molecular fMRI is an advanced form of fMRI that uses contrast agents to detect certain cell pathways and processes, such as dopamine and serotonin. This provides a measurement of signaling in deep brain tissue that can be used for PD. Molecular fMRI expands the detection of specific neurochemical activity for PD on functional and molecular levels (Wei et al., 2021).

FMRI Disadvantages:

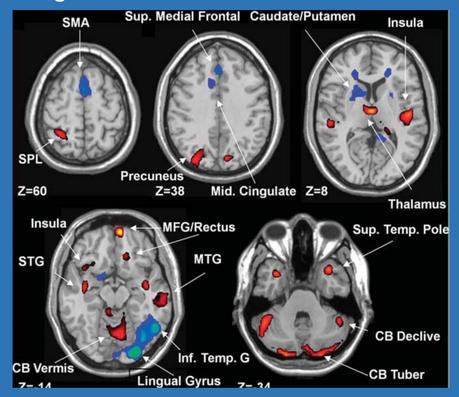
- fMRI is very susceptible to noise, and it needs very complex processing.
- fMRI is not definite/exact, and it is very sensitive to motion; the patient needs to be extremely still during the whole exam.
- fMRI is easily swayed by close-proximity body parts, which could affect the image and data from the imaging (Bidesi et al., 2021).

Figure 3: Dopamine-tracking BOLD

The highlighted parts of the brain are fMRI signals, which show dopamine changes, primarily in areas of the motor cortex and insular cortex (Wei et al., 2021).

Note. From " Molecular fMRI of neurochemical signaling," by Wei, H., Frey, A. M., & Jasanoff, A. *Journal of Neuroscience Methods*, *364*, 109372. (https://doi.org/10.1016/j.jneumeth.2021.109372). Copyright by Elsevier. Reprinted with permission.

Figure 4: PD-related Pattern in Neural Activity in PD Patients and Healthy Controls



This image shows decreased (blue) activation in a very key motor regions (SMA, basal ganglia, thalamus) and increases (red) for compensation for the loss in the main motor functions, which is why fMRI is so valuable because it helps visualize the effects of dopamine loss in brain activity (Bidesi et al., 2021).

Note. From "The role of neuroimaging in Parkinson's disease," by Bidesi, N. S. R., Vang Andersen, I., Windhorst, A. D., Shalgunov, V., & Herth, M. M. *Journal of neurochemistry*, *159*(4), 660–689. (https://doi.org/10.1111/jnc.15516). Copyright by Elsevier. Reprinted with permission.

Conclusion:

Parkinson's disease detection and understanding rely heavily on fMRI and DTI. fMRI assesses brain function at the functional and molecular levels. However, it is limited by complex interpretation and lower specificity compared with molecular fMRI. Molecular fMRI offers greater precision and can highlight specific neural pathways, making it a more effective MRI technique for detecting PD. DTI evaluates white matter in the brain and can identify degeneration in key neural pathways. One example of such degeneration in PD is in the substantia nigra. A limitation of DTI is that it can be influenced by other, similar pathologies, making later stages of PD more difficult to distinguish. Evidence shows that fMRI and DTI cannot definitively diagnose PD on their own, but using both in combination with other tools can provide sufficient evidence for diagnosis. Overall, fMRI's functional and molecular mapping of the brain and DTI's structural assessment can both support early PD diagnosis and improve understanding of its progression. DTI is slightly more useful in the early detection phases for PD because it is easier to differentiate Parkinson's