Discriminative Pattern of Reduced Cerebral Blood Flow in Parkinson's Disease and Parkinsonism-Plus Syndrome: an ASL-MRI study

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Abstract

**Background:** Accurate identification of Parkinson's disease (PD) and Parkinsonism-Plus syndrome (PPS), especially in the early stage of the disease, is very important. The purpose of this study was to investigate the discriminative spatial pattern of cerebral blood flow (CBF) between patients with PD and PPS.

**Methods:** Arterial spin labeling (ASL) perfusion-weighted imaging was performed in 20 patients with PD (mean age 56.35±7.56 years), 16 patients with PPS (mean age 59.62±6.89 years), and 17 healthy controls (HCs, mean age 54.17±6.58 years). Voxel-wise comparison of the CBF was performed among PD, PPS and HC groups. The receiver operating characteristic (ROC) curve was used to evaluate the performance of CBF in discriminating between PD and PPS.

**Results:** PD group showed a significantly decreased CBF in the right cerebelum_crus2, the left middle frontal gyrus (MFG), the triangle inferior frontal gyrus (IFG_Tri), the left frontal medial orbital gyrus (FG_Med_Orb) and the left caudate nucleus (CN) compared with the HC group (P < 0.05). Besides the above regions, the left supplementary motor area (SMA), the right thalamus had decreased CBF in the PPS group compared with the HC group (P < 0.05). PPS group had lower CBF value in the left MFG, the left IFG_Tri, the left CN, the left SMA, and the right thalamus compared with the PD group (P < 0.05). CBFs in left IFG_Tri, the left CN, the left SMA, and the right thalamus had moderate to high capacity in discriminating between PD and PPS patients (AUC 0.719-0.831).

**Conclusion:** PD and PPS patients have certain discriminative patterns of reduced CBFs, which can be used as a surrogate marker for differential diagnosis.

**Background**

Parkinson's disease (PD) and Parkinsonism-Plus syndrome (PPS) are clinically common chronic progressive neurodegenerative diseases in middle-aged and senior population. The known pathological basis of PD is over 50% reduction of dopaminergic neurons in the substantia nigra pars compacta of the midbrain, resulting in a decrease of dopamine production and a relative increase of antagonistic neurotransmitter acetylcholine, which causes hyperfunction. PPS includes a variety of diseases, such as multiple system atrophy (MSA), progressive supranuclear palsy (PSP), and
corticobasal degeneration (CBD). The common feature is the implication of the extrapyramidal system [1–3]. Albeit similar symptoms, clinical treatment for PD and PPS is obviously different [4–6]. Thus, accurate identification of these two types of diseases, especially in the early stage of the disease, is very important [7, 8].

Previously, some brain structural changes on magnetic resonance imaging (MRI) have been shown to be able to differentiate between PD and PPS, such as a cross sign, fissure sign, hummingbird sign, swallow tail sign [9-11]. Unfortunately, these signs mainly occur in the later stage of diseases. Positron emission tomography (PET) and single-photon emission computed tomography (SPECT) can be used for early identification by observing metabolic changes in the brain region. However, it is not widely available and suffers from shortcomings of high cost and radiation hazards [12, 13]. Besides structural MRI, functional MRI has additional value for differential diagnosis [14–18]. Among these functional imaging, arterial spin labeling (ASL)-based perfusion-weighted imaging is a novel, non-invasive method that does not require the injection of contrast agent. Currently, three-dimensional pseudo-continuous arterial spin labeling (3D-pCASL) has been used to measure cerebral perfusion in neurodegenerative diseases quantitatively [19] and demonstrated abnormal cerebral perfusion in PD and MSA [20, 21].

However, whether the spatial pattern of cerebral blood flow (CBF) as measured by ASL imaging is different between patients with PD and PPS remains unclear. In this study, 3D-pCASL was performed in PD and PPS patients to investigate the discriminative spatial pattern of CBF abnormalities in patients with PD and PPS.

Methods
Subjects
From Jan 2017 to Jan 2019, consecutive patients who were clinically diagnosed with PD and PPS were enrolled. The diagnosis of PD was confirmed according to the Clinical Diagnostic Criteria for Parkinson’s Disease in China (2016) [22], and current consensus clinical criteria for PPS [2]. The exclusion criteria were as follows: cerebral hemorrhage, infarction, brain tumors, trauma, severe white matter hyperintensity, contraindication to MRI, and image quality of structural or ASL imaging
ineligible for data analysis. Finally, 20 PD patients including 13 males and 7 females, with a mean age of 56.35 ± 7.56 years (range, 43 to 66 years), and 16 PPS patients including 7 males and 9 females, with a mean age of 59.62 ± 6.89 years (range, 41 to 66 years) were enrolled. 17 healthy controls (HCs) were collected, including 6 males and 11 females, with a mean age of 54.17 ± 6.58 years (range, 44 to 65 years).

MRI acquisition
All participants underwent an MRI examination on a 3.0T scanner (Signa HDxt, GE Medical Systems) with an 8-channel, phased-array head coil. The sequences included axial three-dimensional brain volume T1-weighted imaging (repetition time [TR] = 8.8 ms, echo time [TE] = 3.5 ms, inversion time [TI] = 450 ms, flip angle [FA] = 13°, Matrix = 320 × 320, field of view [FOV] = 240 × 240 mm, number of excitations = 1, slice thickness = 1.2 mm, slice gap = 0 mm) and 3D pCASL. 3D-pCASL images were acquired by using a spiral fast spin echo sequence (TR/TE, 4599 ms/9.8 ms; matrix = 512 × 512; FOV = 240 × 240 mm; number of excitations, 3; slice thickness, 4 mm; and post-labeling delay time, 1525 ms).

Image analysis
All ASL data was transferred to the AW4.6 workstation (GE Healthcare) to generate CBF maps by using GE functool 4.6 software. CBF map was preprocessed by using statistical parametric mapping (SPM, http://www.fil.ion.ucl.ac.uk/spm/software/spm12) based on Matlab2013a platform. Voxel-based analysis (VBA) was applied in this study and the specific processing was similar to those in the literature [23, 24]. At first, the CBF map and 3D T1WI map were manually reoriented to Montreal Neurological Institute (MNI) space and centered on anterior commissure to promote the following segmentation and normalization steps. Then, the T1WI map was co-registered to functional space, and segmented into gray matter, white matter, cerebrospinal fluid. CBF map was further normalized to the standard MNI template (resampling voxel size = 2 mm × 2 mm × 2 mm) with the segmentation information. Finally, spatial smoothing was performed for the normalized CBF map to increase the signal-to-noise ratio (SNR) with a 4 mm full-width at half-maximum (FWHM) isotropic Gaussian kernel.

Statistical analysis
One-way analysis of variance (ANOVA) or χ²-test was used to evaluate the difference in age and
gender among the three groups. Two-sample t-test was applied to compare the differences in disease duration between two patient groups (statistical significance set at $p < 0.05$). ANOVA was used to identify significant between-group differences in the CBF map among the three groups. Correction for multiple comparisons was performed using Gaussian Random Field (GRF) correction with a voxel-level threshold at $p < 0.01$, and cluster-level $p < 0.05$. The Anatomical Automatic Labeling (AAL) brain template was used to report brain regions. The CBF of brain regions with statistically significant difference were extracted for each subject. A post-hoc ANOVA with the least significant difference test (LSD) was used to identify the significance of pair-wise group (PD vs. PPS, PD vs. HC, and PPS vs. HC) differences in CBF value ($p < 0.05$). Receiver operating characteristic (ROC) analysis was used to evaluate the performance of CBF from significant brain regions in differentiation between the PD and PPS groups. Statistical analyses were performed by using the SPSS (version 26.0; SPSS, Chicago, Ill., USA).

Results

**Characteristics of Study Population**

The clinical and demographic information of the PD and PPS patients are shown in Table 1, numerical variables were presented as mean ± standard deviation. All PPS patients initially developed Parkinson's symptoms, including 5 cases of MSA, 2 cases of PSP, 1 case of CBD, and 8 cases of unclassified PPS. There were no statistical differences in gender and age among the PD, PPS and HC groups ($p > 0.05$). The PD and PPS groups had a significant difference in disease duration ($p = 0.02$).

**CBF in the PD, PPS and HC groups**

CBFs in seven central regions were significantly different among the PD, PPS and HC groups (GRF correction, voxel-level threshold $p < 0.01$, cluster level threshold $p < 0.05$). The specific locations of the brain regions are listed in Table 2 and Fig. 1. The further post-hoc analysis showed that PD group had a significantly decreased CBF in the left frontal medial orbital gyrus (FG_Med_Orb), the left triangle inferior frontal gyrus (IFG_Tri), the left middle frontal gyrus (MFG), the right cerebelum_crus2 and the left caudate nucleus (CN), compared with the HC group ($p < 0.05$). Besides the above regions, the left supplementary motor area (SMA), the right thalamus showed decreased CBF in the
PPS group compared with the HC group \((p < 0.05)\). PPS group had lower CBF value in the left IFG_Tri, the left MFG, the left CN, the left SMA, and the right thalamus compared with the PD group \((p < 0.05)\).

**ROC curve analysis**

ROC curve analysis of CBF values in the left MFG, the left IFG_Tri, the left CN, the left SMA, and the right thalamus is shown in Table 3 and Fig. 2. CBF of the left SMA achieved a highest area under the curve (AUC) of 0.831 \((p = 0.001)\), followed by CBF of the right thalamus (AUC: 0.759, \(p = 0.008)\), CBF of the left CN (AUC: 0.725, \(p = 0.022)\), CBF of the left IFG_Tri (AUC: 0.719, \(p = 0.026)\), and CBF of the left MFG (AUC: 0.694, \(p = 0.048)\).

**Discussion**

Our study results showed that both PD and PPS patients had reduced CBF in several brain regions compared with healthy controls. PPS patients had lower CBF in the left MFG, the left IFG_Tri, the left CN, the left SMA, and the right thalamus than PD patients. Further ROC analysis showed that CBF value in these five brain regions had a desirable AUC for discrimination between PD and PPS, with CBF of the left SMA achieving the highest AUC of 0.831.

Previously, arterial spin labeling imaging combined with diffusion tensor imaging has been shown as useful markers for early Parkinson's disease [25]. The arrival time of cerebral arteries in primary Parkinson's disease was found to be prolonged on ASL imaging, indicating abnormal changes in neurovascular status [26, 27]. In our study, 3D-pCASL was performed to measure the cerebral perfusion. Compared with healthy controls, PD showed reduced CBF in five brain regions, i.e., the right cerebelum_crus2, the left MFG, the left IFG_Tri, the left FG_Med_Orb, and the left CN. These results were consistent with previous imaging studies in PD patients using PET/SPECT and ASL [28–33], where hypoperfusion was found in widespread cortical regions [20, 28], particularly in frontal regions [28, 29–31], as well as CN [28], cerebellar regions [33]. Compared with healthy control, the CBF value of frontal regions in PD patients decreased 11.4–15.9\% in our study. This reduction of brain perfusion is similar to previously reported 9.4\%-20.8\% in PD patients [20, 28]. Frontal lobe dysfunction is a well-known character for PD patients [34]. These areas are often associated with motor function, and cognitive impairments or depression in PD [35, 36] and hypoperfusion in the
prefrontal region might lead to emotional and cognitive disorders [37, 38]. In addition, our study also showed hypoperfusion in the left CN and the right cerebelum_crus2 in PD patients. Previously, significant hypoperfusion was detected in the right and left CN in patients with PD by using ASL technique [26, 28]. The hypoperfusion of CN maybe relate to the dopamine loss in the CN, which is associated with the cognitive decline [39] and depressive symptoms [40] in PD. Furthermore, the CBF laterality pattern in the CN was reported to a biomarker for PD diagnosis [41]. The cerebellum is an important component in motor control. Whereas, contradictory results have been reported for the cerebellum CBF change in the PD; thus, the exact role of the cerebellum in PD remains to be further understood [33].

The early-middle stage of PPS is challenging to differentiate from PD in terms of clinical symptoms. Previously, SPECT and PET-CT have been used to discriminate PD from parkinsonian disorders, such as Parkinson variant of MSA and PSP [42, 43]. These patients showed a distinct hypoperfusion pattern in the frontal cortex, thalamus, and cerebellum [42]. In our study, 3D pCASL imaging was used to determine the CBF changes in PPS patients. Our results showed that PPS had reduced CBF in five brain regions similar to those of PD and two additional brain regions, i.e., the left SMA and the right thalamus. Comparatively, the PPS group had altered CBF in more widespread brain regions. The additional involvement of these two brain regions suggests that PPS patients might have more severe impairment of motor function than PD patients. It is known that the extrapyramidal system includes a cortical-ponto-cerebella-thalamocortical circuit [44]. The cerebellum, thalamus and SMA play essential role in the cerebella-thalamocortical circuit and participant in motor control [45]. The association between the hypoperfusion in the cerebellum, thalamus, SMA and the damage in the extrapyramidal system has been described in PPS patients [46]. Thus, more widespread and severe impairment of CBF in PPS might reflect more severity of PPS or later stage of disease.

Our study showed that PPS patients had lower CBF values in the left IFG_Tri, the left MFG, the left CN, the left SMA, and the right thalamus compared with PD patients. This different pattern of reduced brain perfusion between PPS and PD is consistent with the previous study, where the perfusion distribution patterns were found to be different among MSA-P, PSP and PD [47]. More obvious
impairment of CBF might reflect a more severe brain damage in the PPS group. Indeed, neuropsychiatric symptoms are common in patients with PPS; and the incidence and prevalence of depressive symptoms were higher in atypical parkinsonian syndromes and also appear to be more severe than in PD [48, 49]. MSA patients have glial cytoplasmic inclusions in the motor region and SMA, which is responsible for bradykinesia [50]. In our study, further ROC analysis showed that CBF value in these five brain regions had a desirable AUC for discrimination between PD and PPS, with CBF of the left SMA achieving the highest AUC of 0.831. Previously, a multitude of imaging parameters have been used to differentiate between PD and PPS [9, 52–54]. Tir et al. found that PSP had a lower fractional anisotropy value derived from diffusion tensor imaging in the SMA, indicating an abnormal motor pathway in PSP [51]. Calloni et al. reported that the middle cerebellar peduncle width and putaminal hypointensity on susceptibility-weighted imaging (SWI) can be used in combination to distinguish atypical parkinsonisms from idiopathic PD, with an AUC = 0.98 [52]. In addition, swallow tail (AUC = 0.85) and putaminal hypointensity (AUC = 0.68) also were reported to be able to distinguish MSA from PD [9]. Comparatively, the participants in these studies were older and had longer disease duration. In our study, PPS patients in the earlier stage of the disease were included. Our results showed the CBF of the SMA had the greatest AUC (0.831) and might be used as a surrogate marker for the differential diagnosis between the two diseases in an earlier stage. There are some limitations to this study. First, we did not investigate CBF in early PD patients. The CBF as detected by ASL has been reported in early PD patients and perfusion reduction did not differ among different stages of PD [25]. Second, the sample size is small. The numbers of clinical scales collected are insufficient. Further large-scale, longitudinal studies and correlation analysis are needed to validate the discriminative CBF in these two diseases.

Conclusion
In conclusion, our study demonstrated that PD and PPS patients showed hypoperfusion in several brain regions and PPS showed severer and more widespread impairment in CBF. PD and PPS patients have a certain discriminative pattern of reduced CBFs, in particular, reduced CBF left SMA, which can be used as a surrogate marker for differential diagnosis.
Declarations

*Ethics approval and consent to participate*

This prospective study was approved by the institutional research ethics board of Guangdong 999 Brain Hospital (Guangzhou, China), and written informed consent was obtained from all participants.

*Consent for publication*

Not applicable.

*Availability of data and materials*

The datasets analysed during the current study are available from the corresponding author on reasonable request.

*Competing interests*

The authors declare that they have no competing interests.

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*Authors’ contributions*

Lina Cheng: Methodology, Writing - Original Draft, Funding acquisition. Xiaoyan Wu: Software, Validation, Writing - Review & Editing. Ruomi Guo: Investigation. Yuzhou Wang: Investigation, Resources. Wensheng Wang: Project administration. Peng He: Formal analysis. Hanbo Lin: Data Curation. Jun Shen: Conceptualization, Writing - Review & Editing.

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*Abbreviations*
PD: Parkinson's disease; PPS: Parkinsonism-Plus syndrome; MSA: Multiple system atrophy; PSP: Progressive supranuclear palsy; CBD: Corticobasal degeneration; MRI: Magnetic resonance imaging; PET: Positron emission tomography; SPECT: Single-photon emission computed tomography; ASL: Arterial spin labeling; 3D-pCASL: Three-dimensional pseudo-continuous arterial spin labeling; CBF: Cerebral blood flow; HCs: Healthy controls; TR: Repetition time; TE: Echo time; TI: Inversion time; FA: Flip angle; FOV: Field of view; VBA: Voxel-based analysis; MNI: Montreal Neurological Institute; SNR: Signal-to-noise ratio; FWHM: Full-width at half-maximum; ANOVA: One-way analysis of variance; GRF: Gaussian Random Field; AAL: Anatomical Automatic Labeling; LSD: Least significant difference test; ROC: Receiver operating characteristic; FG_Med_Orb: Frontal medial orbital gyrus; IFG_Tri: Triangle inferior frontal gyrus; MFG: Middle frontal gyrus; CN: Caudate nucleus; SMA: Supplementary motor area; AUC: Area under the curve; SWI: Susceptibility-weighted imaging.

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Tables

| Table 1. Demographic and clinical characteristics of the participants |
|------------------|-------|-----------------|-----------------|-----------------|
| Characteristics  | PD (n=20) | PPS (n=16) | Control (n=17) | p-Value |
| Age, years       | 56.35±7.56 | 59.62±6.89 | 54.17±6.58 | 0.094^a |
| Gender, male/female | 13/7 | 7/9 | 6/11 | 0.174^b |
| Disease duration years | 6.40±4.04 | 3.50±2.81 | NA | 0.020^c |

Abbreviations: ^a One-way ANOVA; ^b Chi-square ($\chi^2$) test; ^c Two-sample t-test; PD, Parkinson's disease; PPS, Parkinsonism-Plus syndrome.

| Table 2. CBF in brain regions different among the PD, PPS, and HC groups |
### Peak location (AAL-90)

|            | MNI coordinate | No. of voxels | Peak F-value | HC          | PD          |
|------------|----------------|---------------|--------------|-------------|-------------|
|            | x   | y   | z   |              | Mean/SD     | Mean/SD     |
| SMA.L      | -2  | 24  | 60  | 481         | 3.73        |             |
| THA.R      | 1   | -16 | 5   | 313         | 3.74        |             |
| FG_Med_Orb.L | 0  | 64  | -4  | 646         | 3.82        |             |
| IFG_Tri.L  | -52 | 20  | 2   | 580         | 3.88        |             |
| MFG.L      | -40 | 26  | 40  | 377         | 3.93        |             |
| Cere_Crus2.R | 50 | -66 | -50 | 622         | 4.25        |             |
| CN. L      | -10 | 4   | 12  | 457         | 4.56        |             |

**Abbreviations:** CBF, cerebral blood flow; AAL, automated anatomical labeling; HC, healthy controls; PD, Parkinson's disease; PPS, Parkinsonism-Plus syndrome; SMA, supplementary motor area; THA, thalamus; FG_Med_Orb, frontal medial orbital gyrus; IFG_Tri, triangle inferior frontal gyrus; MFG, middle frontal gyrus; Cere_Crus2, cerebellum_crus2; CN, caudate nucleus; L (R), left (right) hemisphere; SD, standard deviation.

### Table 3. ROC analysis of CBF for differentiation between the PD and PPS groups

| Brain region | AUC   | Cutoff point | Sensitivity (%) | Specificity (%) | 95% CI | p-val |
|--------------|-------|--------------|-----------------|-----------------|--------|-------|
| SMA.L        | 0.831 | 33.723       | 0.800           | 0.750           | 0.696  | 0.967 | 0.00 |
| THA.R        | 0.759 | 50.195       | 0.750           | 0.812           | 0.597  | 0.922 | 0.00 |
| CN. L        | 0.725 | 24.544       | 0.900           | 0.625           | 0.547  | 0.903 | 0.02 |
| IFG_Tri.L    | 0.719 | 39.483       | 0.650           | 0.875           | 0.545  | 0.892 | 0.02 |
| MFG.L        | 0.694 | 44.581       | 0.550           | 0.937           | 0.521  | 0.866 | 0.04 |

**Abbreviations:** ROC, receiver operating characteristic; PD, Parkinson's disease; PPS, Parkinsonism-Plus syndrome; AUC, area under the curve; CI, confidence interval; SMA, supplementary motor area; THA, thalamus; CN, caudate nucleus; IFG_Tri, triangle inferior frontal gyrus; MFG, middle frontal gyrus; L (R), left (right) hemisphere.

**Figures**
The significant differences of CBF between the PD, PPS, and HC groups. (a) Brain regions of CBF differences between the PD, PPS and HC groups. (b) The bar plot shows the pair-wise contrasts in CBF value between the three groups. The bar height corresponds to the mean value of the CBF and the error bar to the standard deviation for each group. Abbreviations: SMA, supplementary motor area; THA, thalamus; FG_Med_Orb, frontal medial orbital gyrus; IFG_Tri, triangle inferior frontal gyrus; MFG, middle frontal gyrus; Cere_Crus2, cerebellum_crus2; CN, caudate nucleus; L (R), left (right) hemisphere; PD, Parkinson’s disease; PPS, Parkinsonism-Plus syndrome; HC, healthy controls. *p < 0.05; **p < 0.01; ***p < 0.001.
Figure 2

ROC curves of CBF in the regions with a significant between-group difference for distinguishing PD patients from PPS patients. The diagonal line (grey line) represents the area under the curve of 0.50. Abbreviations: ROC, receiver operating characteristic; SMA, supplementary motor area; THA, thalamus; CN, caudate nucleus; IFG_Tri, triangle inferior frontal gyrus; MFG, middle frontal gyrus; L (R), left (right) hemisphere; PD, Parkinson's disease; PPS, Parkinsonism-Plus syndrome.