Cortical Magnetic Susceptibility in Multiple Sclerosis in MRI: Characterization of Visual and Motor Areas and Comparison with Structural and Diffusion Measurements

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BACKGROUND AND AIMS

Quantitative Susceptibility Mapping (QSM) is an advanced MRI technique used in multiple sclerosis (MS) research for its ability to detect demyelination in white matter and iron accumulation in deep gray matter nuclei [1]. This study aims to examine magnetic susceptibility (χ) in cortical areas associated with visual and motor functions, comparing susceptibility distributions between MS patients and healthy controls, and assessing changes in this measure relative to other imaging parameters. In addition to comparing structural data, QSM data were correlated with SANDI (Soma And Neurite Density Imaging), an advanced diffusion technique designed to reconstruct in vivo microstructural information in gray matter [2]. In the context of MS, SANDI has been used to measure cortical inflammation and degeneration [3].

METHODS

The study sample included 64 MS patients and 17 healthy controls (Tab.1)
All participants underwent 3T MRI (Siemens MAGNETOM Prisma scanner), including the following sequences:

- 3D T_1w MP2RAGE (1 mm isotropic, TR/TE/TI1/TI2 = 5000/2.9/700/2500 ms)
- 3D T_2w FLAIR (1 mm isotropic, TR/TE/TI = 5000/393/1800 ms)
- PSGE for SANDI (2 mm isotropic, 213 gradient directions, b = 0,500,1000,2000,3000,4000,6000 s/mm², TE/TR= 80 ms/2600 ms, δ = 24.66 ms, Δ = 39.07 ms)
- EPI for QSM (0.65 mm isotropic, TR/TE = 64/35 ms)

PSGE images were processed following Schiavi's protocol (2023) to reconstruct maps of soma density, neurite density, and extracellular space. QSM maps were generated using Laplacian unwrapping, V-SHARP for background removal, and iLSQR for dipole inversion, using cerebrospinal fluid as a reference. White matter lesions were segmented automatically via a deep learning algorithm, and T1 images were processed with FastSurfer for cortical parcellation, focusing on regions such as the precentral and postcentral gyri, cuneus, precuneus, and pericalcarine cortex. Additional regions were taken from the Human Motor Area Template [4], including the supplementary motor area (SMA), pre-supplementary area (pre-SMA), dorsal premotor cortex (PMd), and ventral premotor cortex (PMv). Magnetic susceptibility, volume, and SANDI metrics were extracted (Fig.1).

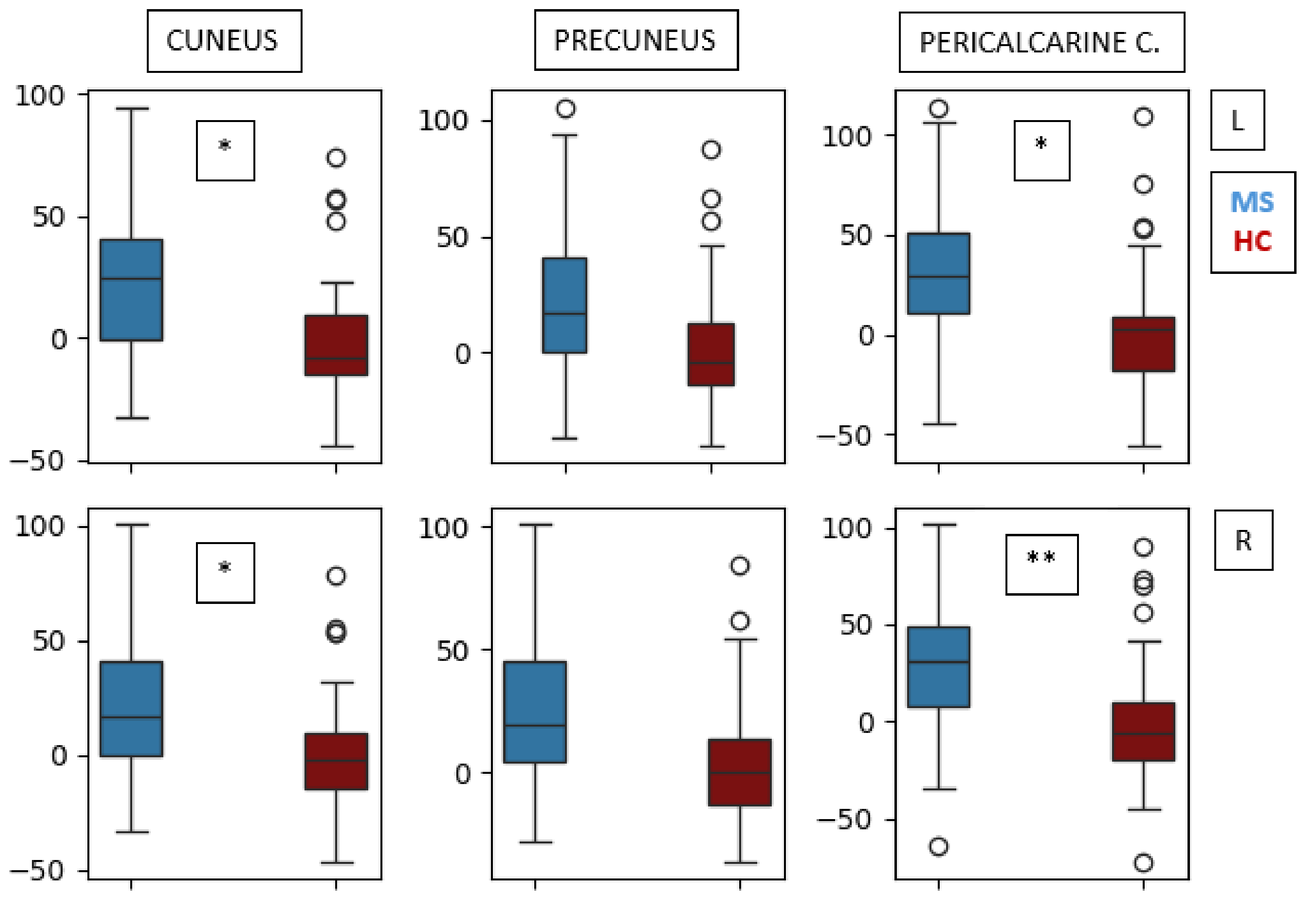

Figure 2: comparison of susceptibility distribution between patients with MS and healthy controls

ANCOVA (sex, age, TIV as covariates)
$p < .05$ * < .01 **

	HC	MS	*p-value*
#	27	58	--
F:M	19:9	40:24	.119
Age (y) (μ ± σ)	39 ± 13	44 ± 13	.633
Clinical phenotype (RR:SP)	--	53:11	--

Table 1: Demographic characteristics of healthy controls and patients with MS (RR = relapsing remitting; SP = secondary progressive)

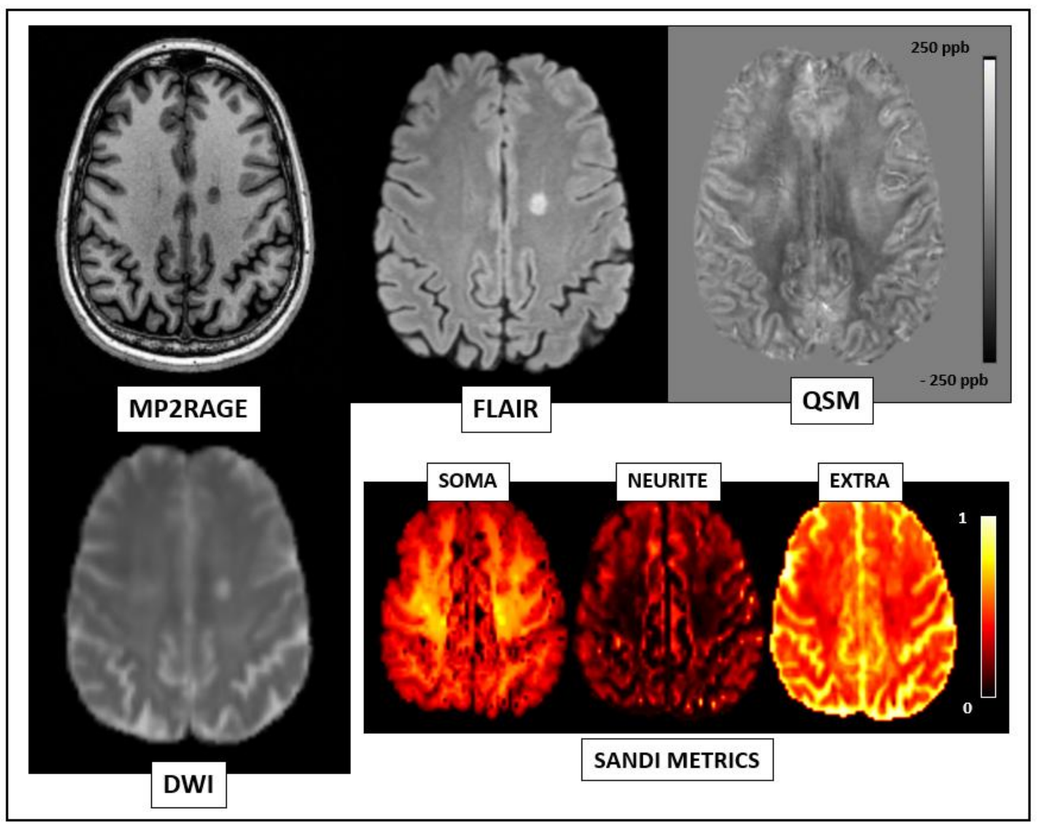

Figure 1: MR sequences and metrics (MS RR, F/46yo)

RESULTS

- **Increase in magnetic susceptibility** (Fig.2) in the cortical areas of MS patients compared to healthy controls, affecting both motor and visual regions
- Significant increase of susceptibility in visual areas:
  cuneus (*p* .015 L and .012 R); pericalcarine cortex (*p* .016 L and .003 R)
- No significant correlations susceptibility - volume
- Significant **negative correlation between magnetic susceptibility and soma density** (Fig.3) in several cortical areas:
  precentral gyrus (M1) (p .015 L and 0.006 R); postcentral gyrus (S1) (p 0.016 L and 0.008 R); PMd (p .016 L and .014 R), PMv (p .009 L and .003 R); and precuneus (p .022 L and .016 R).
  Even in regions without statistical significance, the negative trend supported the inverse relationship between magnetic susceptibility and soma density.

Spearman's test - p < .05 * < .01 **

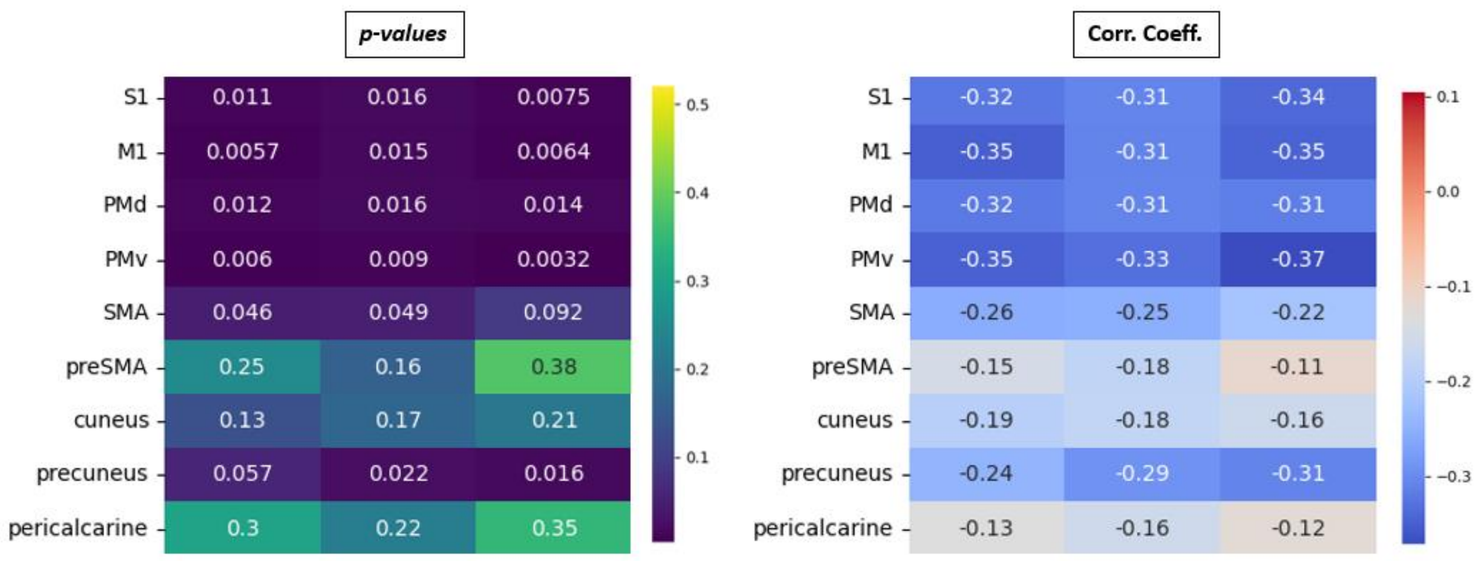

Figure 3: correlation between magnetic susceptibility and soma density in cortical areas

CONCLUSION

The study suggests that QSM is a promising tool for investigating cortical changes in MS patients. The results indicate that increased cortical magnetic susceptibility is a characteristic of the disease, particularly in gyri associated with visual functions. The lack of correlation with volume suggests that susceptibility changes may precede cortical atrophy. Susceptibility, which increases with neurodegenerative severity, shows a negative correlation with soma density, whose reduction observed in MS patients, as noted in previous studies [4], aligning with a general process of cortical degeneration.

[1] Voon et al. Neuroimage Clin 2024
[2] Schiavi et al. Hum Brain Mapp 2023
[3] Barakovic et al. Sci Rep 2024
[4] Mayka et al. Neuroimage 2006