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Swallow Tail Sign: Revisited

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T he loss of the radiologic swallow tail sign on MRI scans of the substantia nigra is a promising diagnostic marker of Parkinson disease (1), although its anatomic underpinning is unclear. An early influential study showed that the hyperintense inner part of the swallow tail sign on T2*-weighted images (STh) corresponds to iron-poor areas in substantia nigra and suggested it to equal nigrosome 1, the dopaminergic region affected earliest and strongest in Parkinson disease (2). This would render the STh a cellularly specific marker (2). However, recent postmortem tissue studies have challenged this interpretation, reporting that nigrosome 1 is hypointense in T2*-weighted images (3,4). We combined three-dimensional histology with 7-T in vivo and postmortem MRI to demonstrate that nigrosome 1 and the radiologic STh are partially overlapping but distinct.

Materials and Methods

In this secondary analysis of prospectively collected data, 7-T in vivo MRI (5) was combined with 7-T postmortem MRI, three-dimensional block-face imaging, and immunohistochemistry (6). The local ethics committees approved all studies.

From March to December 2017, in vivo T2*-weighted images with 0.4-mm isotropic resolution were acquired in three randomly chosen healthy volunteers with no contraindication to ultra-high-field MRI investigation to match the number of postmortem specimens (Fig 1) (5).

Postmortem T2*-weighted images were acquired, using a similar protocol and the same resolution as for in vivo images, of three whole heads (specimens 1, 7, and 8 in a previous study (6)) and complemented by high-quality histochemistry in the substantia nigra (Fig 2). Brain specimens from donors with no record of neurologic disease were sourced through a whole-body donation program. Written informed consent for whole-body donation had been provided before death.

To assess intrarater reliability, one author (P.A.G., with 9 years of experience in MRI in Parkinson disease) delineated the STh twice on in vivo T2*-weighted images (Figs 1B, 2B).

A neuroanatomist (M.M., with 20 years of experience) and a trained research assistant (C. Jantzen, with 1 year of experience) segmented areas with a high density of neuromelanin-pigmented dopaminergic neurons on block-face images (resolution, 150 × 150 × 200 μm³) while blinded to the STh delineation. Nigrosome 1 was defined as a subvolume with the characteristic “stripe” morphology (2) (Fig 1D, 1E). It agreed with the classic definition of nigrosome 1 based on low anticalbindin immuno-reactivity (not shown here).

In vivo and postmortem T2*-weighted MRI scans and block-face images were affinely registered based on anatomic landmarks, including small vessels, outside the substantia nigra. Before comparing STh and nigrosome 1, segmentations were smoothed with a kernel reflecting the registration error (0.46 mm, Fig 1). One author (M.B., with 5 years of experience) assessed size differences using the Student t test. Two-tailed P < .05 was indicative of a statistically significant difference.

Results

Three female participants (mean age, 30 years ± 1 [SD]) and three postmortem brains (mean age, 78 years ± 3; two male donors) were evaluated.

Although the STh was ovoid-shaped for all participants, nigrosome 1 was consistently flat and disk-like (Fig 1E). Nigrosome 1 was significantly thinner (P < .001) and longer (P < .003) than the STh (Fig 2F).

Coregistration of in vivo and postmortem T2*-weighted MRI scans to block-face images showed that nigrosome 1 only partly overlapped with STh for all possible combinations of data sets across participants and specimens. Nigrosome 1 extended beyond the STh...
Our study had limitations, including the small number of histologic samples and the age and sex differences between in vivo participants and donors of the postmortem specimens. The neuroanatomic cellular underpinnings of the radiologic STh and its disappearance in Parkinson disease must be further investigated. The nonequivalence of STh and nigrosome 1 does not affect the value of STh as a late-stage Parkinson disease biomarker. However, a more accurate link of MRI features and the substantia nigra anatomy is expected to improve Parkinson disease diagnostics and disease monitoring.

Acknowledgments: We thank Patrick Scheibe, PhD, for his help with data visualization and Rawien Balesar, MSc, for sharing his histology expertise. We thank the whole-body donors and acknowledge the whole-body donation program at the University of Maastricht for providing postmortem brain samples.

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Discussion
We showed that the widespread equation of the STh and nigrosome 1 is inaccurate because they are only partially overlapping. Therefore, STh and nigrosome 1 probably correspond to distinct structures and should not be used synonymously.

The hypointense appearance of nigrosome 1 on postmortem T2*-weighted images, unlike the hyperintense STh, is consistent with findings of postmortem tissue studies (3,4). It is unclear why nigrosome 1 has not been reported as a hypointense structure on in vivo scans, but causes may include an insufficient contrast-to-noise ratio, image artifacts, or different contrast mechanisms in nigrosome 1 between in vivo and postmortem imaging.

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