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Delineating the human direct and indirect motor descending pathways using high-resolution tractography with diffusion imaging

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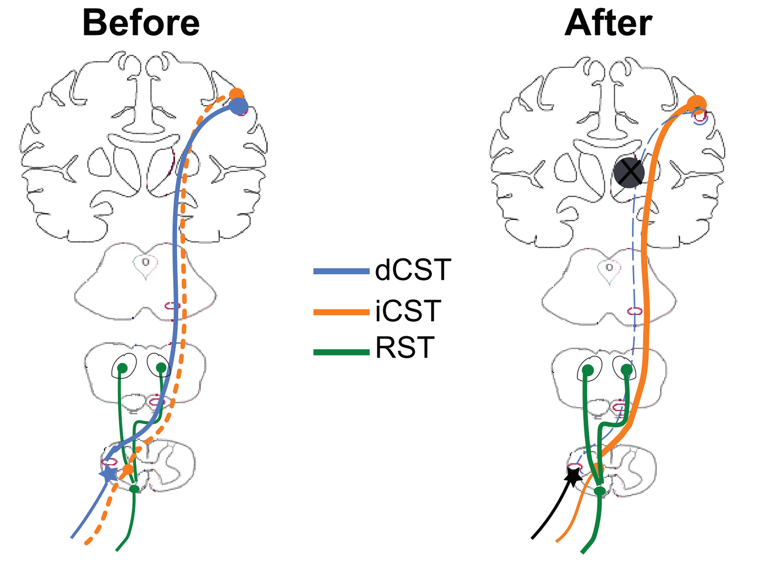
Introduction

Dexterous hands are essential in our daily activities. Previous studies have established that fine finger control and hand strength are supported by separate descending pathways, namely, the corticospinal (CST) and reticulospinal tracts (RST) (Lawrence & Kuypers, 1968a&b; Xu et al., 2017). Non-human primate research also suggests that after lesion of the direct, corticomotoneuronal projections within the CST (dCST), the indirect connections within the CST (iCST), specifically the propriospinal (PN) pathway, also contributes to the recovery of hand dexterity (Isa, 2019). Moreover, reticulospinal tract (RST) has also been found to particpate or set a limit to dexterity recovery (Zaaimi et al., 2012).

Delineating these descending pathways will be informative to functional recovery after neurological insult. Comparative fiber tracking studies across species suggests that the majority of the dCST in humans originates from M1 (Brodmann's area BA4) (Lassek & Rasmussen, 1940) and the PN pathway mainly originate from ventral premotor cortex (PMv) (BA6) (Pierrot-Deseilligny, E. & Burke, 2005).

Here we investigate the feasibility of using a recent ultra-high-resolution whole-brain atlas from the HCP data to separate dCST, iCST, and RST in healthy participants and stroke survivors.



Hypothesized Model

A hypothesized model of three descending pathways (dCST, iCST and RST) showing disruption of the neural pathway before and after the stroke incident.

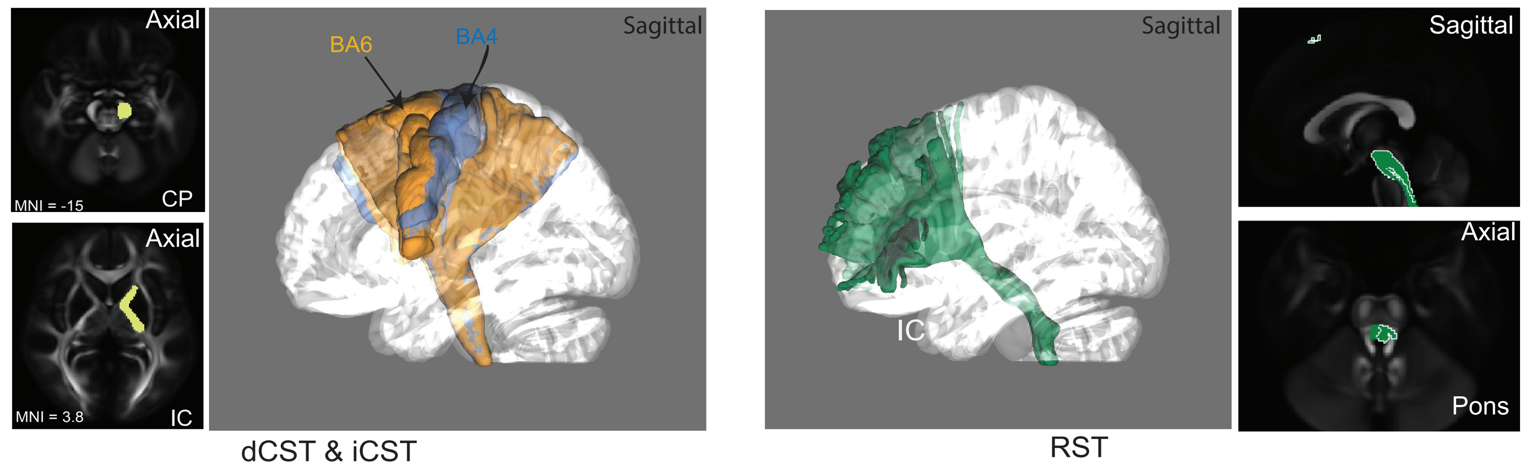
In stroke: after a disruption of the dCST, iCST and RST may be upregulated to compensate the loss of the direct pathway.

Methods

Participants: Healthy younger adults (N=6; 5 females, mean age 19), older adults (N=8; 4 females; mean age 71 years) and individuals with stroke (N=2; 2 females; mean age 58 years).

Diffusion Imaging: The diffusion Magnetic Resonance images (dMRI; 60 directions, b=2000 and 4000 s/mm^2, slice thickness of 2 mm) was collected from each subject on a 3T GE scanner (Discovery MR750) at the University of Georgia. We used readout-segmented echo-planar imaging in conjunction with parallel imaging (Heidemann et al., 2010) and a multi-shell diffusion spectrum imaging sequence. The dMRI images were reconstructed to the MNI space using q-space diffeomorphic reconstruction (QSDR) at an output resolution of 1 mm isotropic in a standard atlas space for easy comparison across subjects using DSI studio (Yeh et al., 2010).

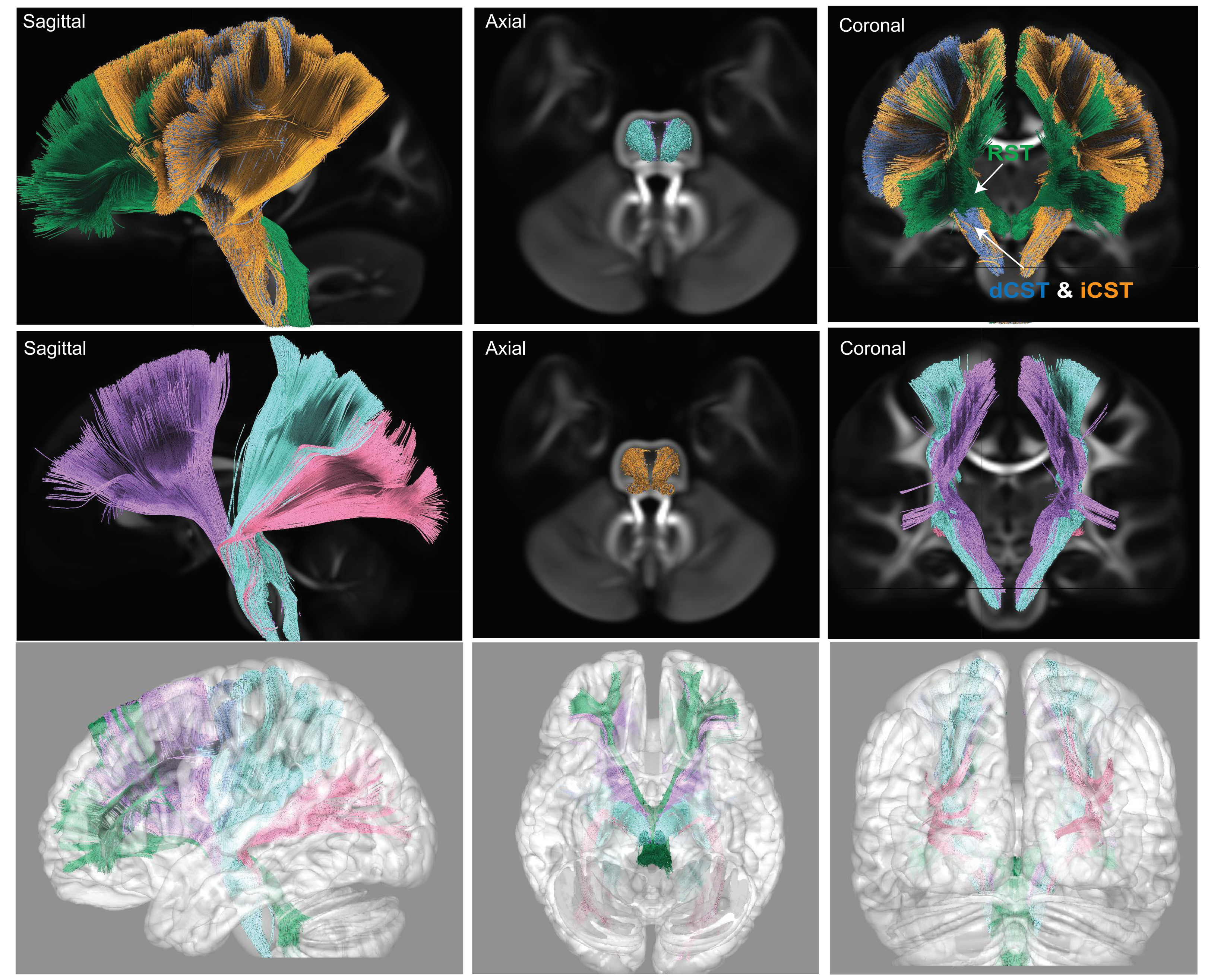
Fiber Tracking: To acess the tract integrity of different pathways affected by the lesion, we adopted the technique from previous studies and generated the three different ROI masks to approximate the direct, indirect CST and RST pathways in the HCP atlas.



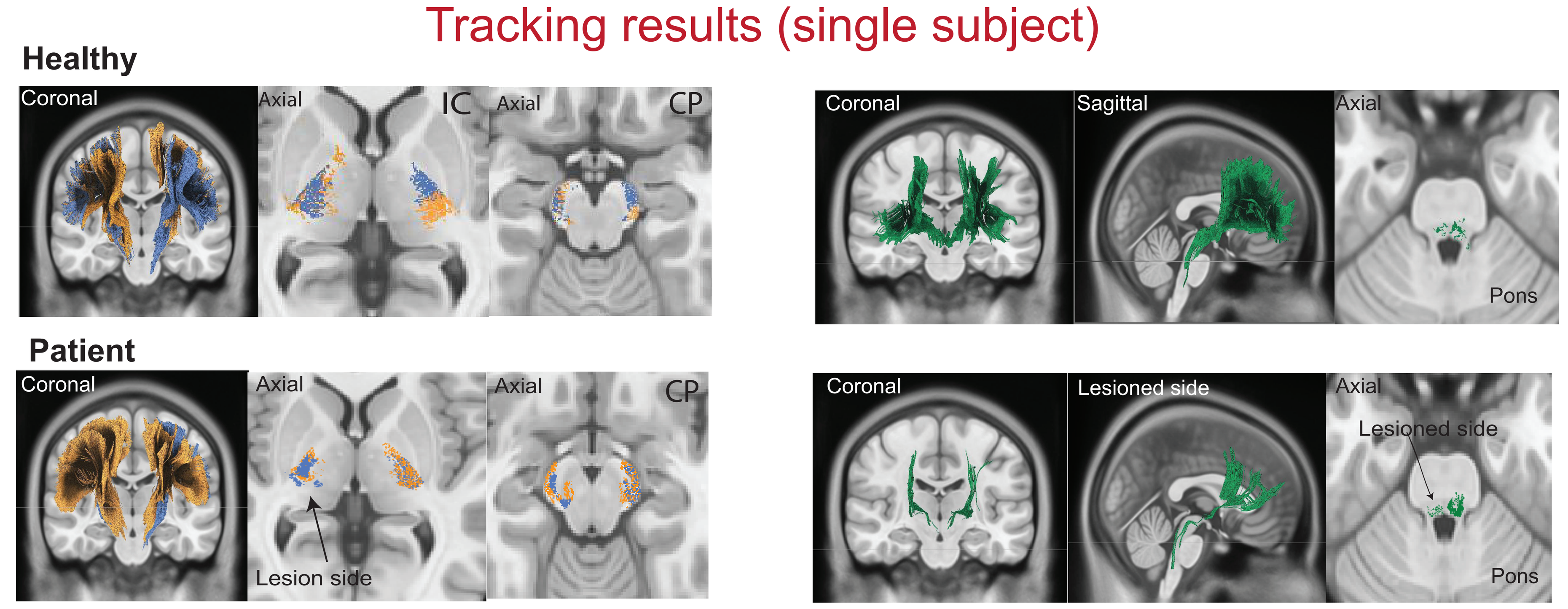
ROIs masks were created in the MNI template space of the HCP data. The direct and indirect CST ROI masks were restricted by BA4 (direct), BA6 (indirect), starting from the internal capsule (IC) and between the cortex and cerebral peduncle (CP). Two ROI masks for the RST pathways were seeded in the posterior segment of the brainstem, behind and dorsal to the pons.

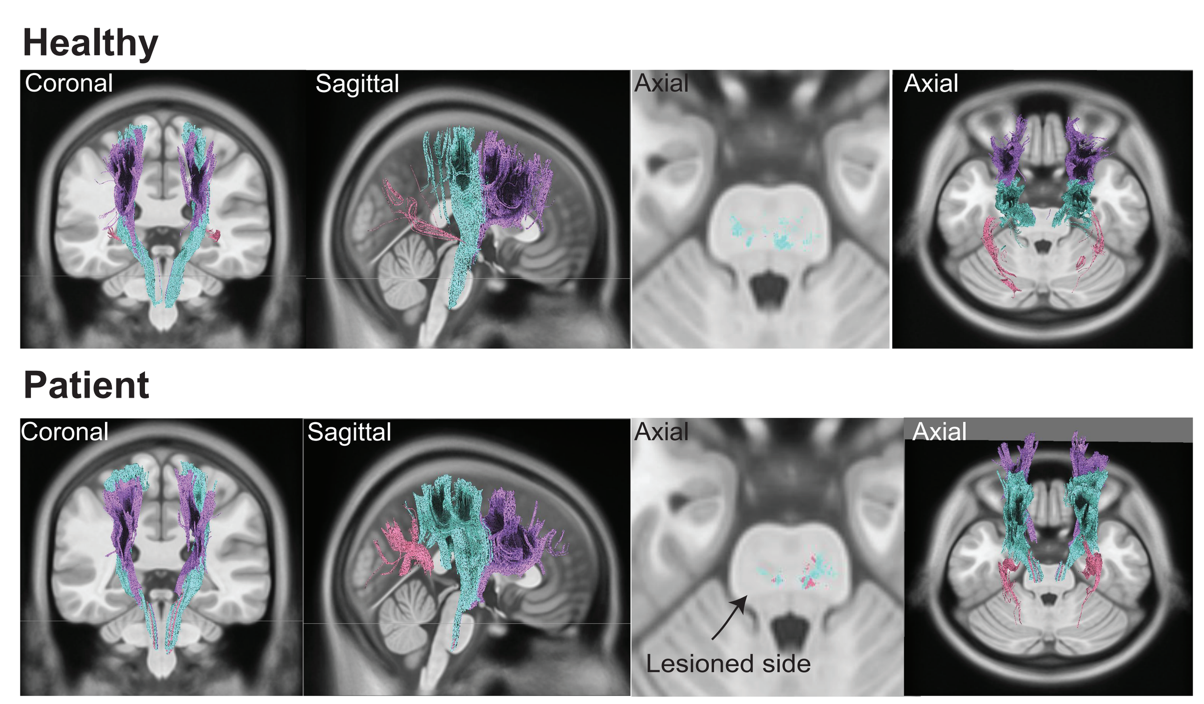
Atlas: dCST, iCST RST, CPT

The decending tracts, direct direct CST (dCST), indirect (iCST), reticulospinal (RST), and cortico-pontine (CPT) tracts are mapped in the HCP1065 average data as shown in coronal, sagittal and isosurface view.



Tracking results (single subject)





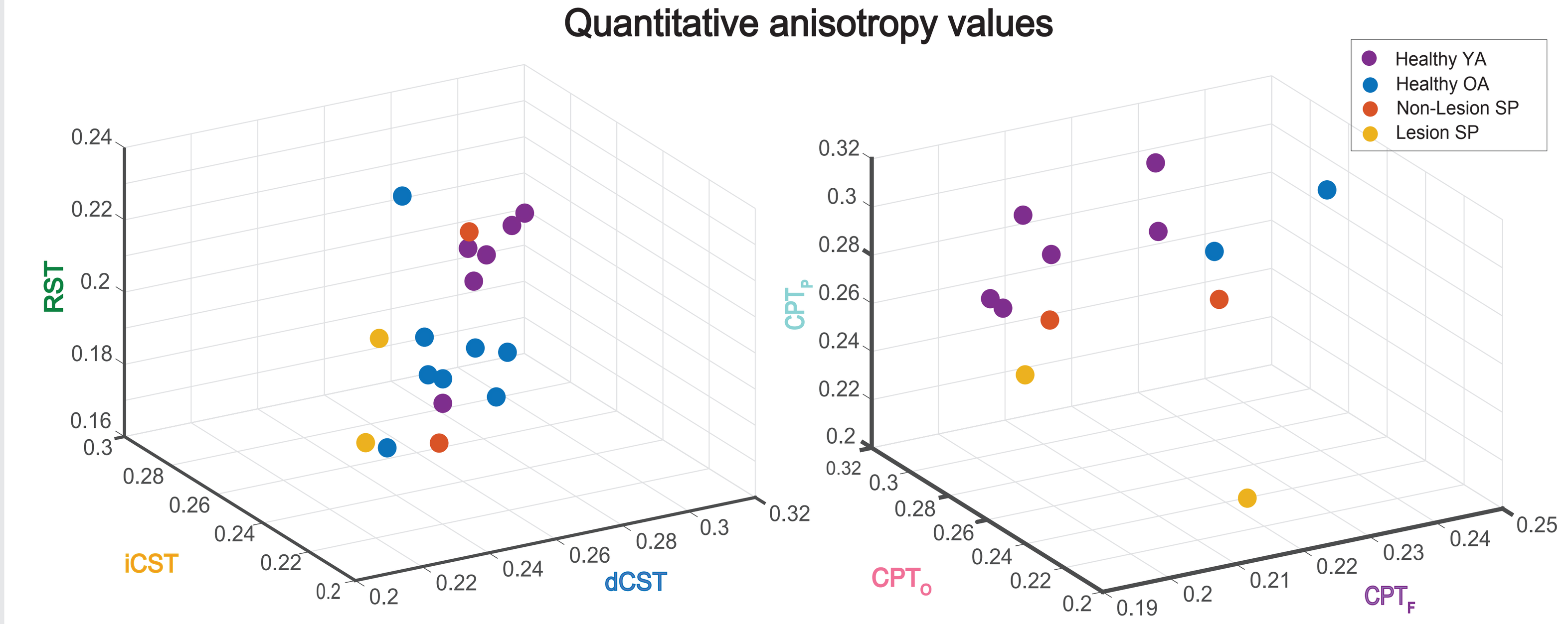
In a healthy older adult (OA) ICBM template, CST tracts (dCST and iCST) are restricted using ROI masks starting at internal capsule (IC) and cerebral peduncle(CP).

All tracts (dCST, ICST, RST and CPT) are restricted using same ROI masks starting at IC and CP (dCST; iCST).

RST and CPT as shown in both single subject's template space and single stroke patient's lesioned and non-lesioned hemisphere.

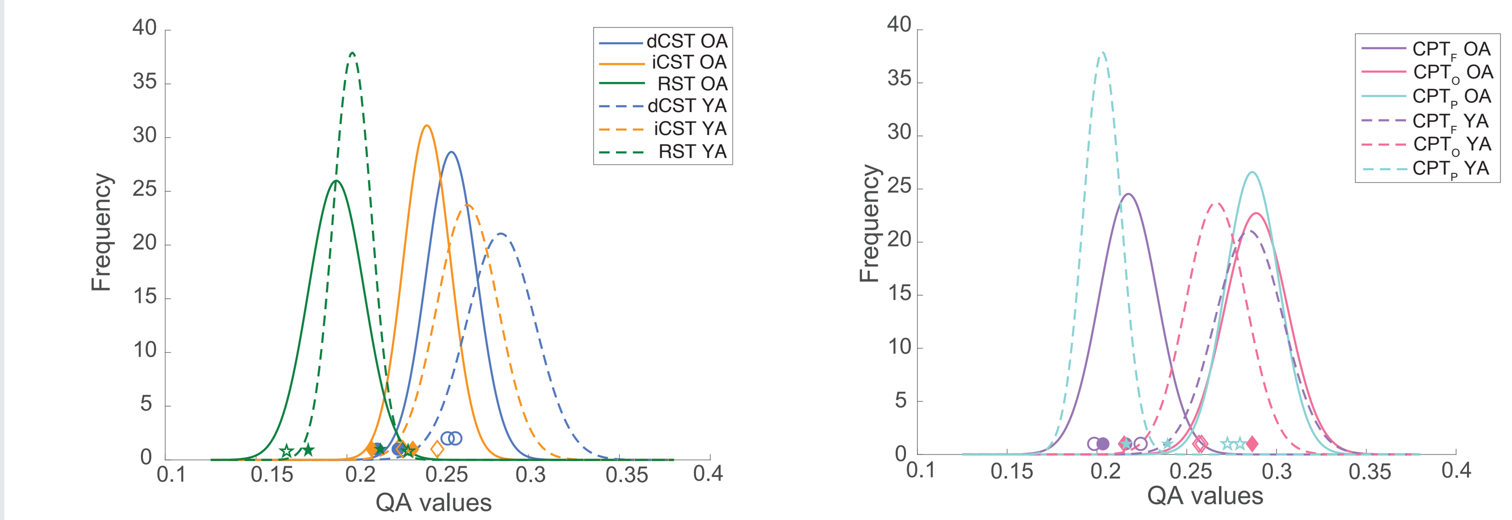
Tracking results (group)

Quantitative anisotropy values



Scatter plots of the QA values for decending tracts, dCST, iCST and RST for three groups: younger adults (YA), older adults (OA) and stroke patient (SP). Stroke sursivors show lower values in all tracts.

Distribution of QA values



QA values for the lesioned side (filler markers) and non-lesion side (open markers) of the stroke survivors are plotted in the YA and OA distributions of all four descending pathways (dCST, iCST, RST, and CPT).

Discussions

The QA values of two-stroke patients' lesioned side were at the lower end of the QA distributions of the healthy participants.

Our method is shown to be effective delineating three essential descending pathways for hand dexterity: the direct and indirect CST, RST, and effectively access the fiber integrity in these pathways.

For the next step, more fine-tuned ROI masks will all be further explored in a larger sample of stroke survivors.

References

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Awknowledgement

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