



Case report

Recurrent ipsilateral hemiparesis in a patient with both uncrossed corticospinal tracts and reorganization of cortical motor areas – An opportune visitation of the motor tracts



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ARTICLE INFO

Article history:

Received 20 April 2020

Accepted 15 January 2021

Keywords:

Ipsilateral hemiparesis

Diffusion tensor imaging tractography

Functional magnetic resonance imaging

Transcranial magnetic stimulation

ABSTRACT

We report the case of a patient who experienced recurrent ipsilateral hemiparesis in the setting of predominantly-uncrossed corticospinal tracts, with concomitant neuronal reorganization of the cortical motor maps, and the presence of aberrant interhemispheric connections. Their presence was supported by our results from diffusion tensor imaging tractography, functional magnetic resonance imaging, and transcranial magnetic stimulation. To our knowledge, this has never been reported before, and provides valuable insights into the mechanisms behind post-stroke motor recovery.

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1. Case presentation

Our patient is a 52-year-old woman who presented with episodic left-sided weakness lasting 10 min each, occurring once to twice a week for over a month. She had a history of poorly-controlled diabetes mellitus, hypertension, hyperlipidaemia and an occipital arachnoid cyst. She does not smoke, and has no prior cardiovascular or cerebrovascular disease. The weakness was severe, involving her entire left upper and lower limbs, rendering her unable to move them against gravity. She recovered fully after each episode. They were unrelated to positional changes, and were without sensory deficits or headaches.

She was asymptomatic upon presentation. Her blood pressure and heart rate were 126/84 mmHg and 88 bpm respectively. Neurologic examination was unremarkable and she was without weakness. A preliminary diagnosis of a recurrent left-sided motor transient ischemic attack (TIA) was established. Magnetic Resonance Imaging (MRI) revealed a chronic lacunar infarct at the right centrum semiovale (CS), and a right occipital arachnoid cyst measuring $3.2 \times 2.1 \times 3.7$ cm. There was no acute infarction and the corpus callosum appeared normal. However, MR angiography (MRA) showed a severely-stenotic left cavernous internal carotid

artery (ICA) on a background of atherosclerosis (Fig. 1), while the right-sided vasculature was without significant stenosis.

Suspecting ipsilateral hemiparesis, the patient underwent diffusion tensor imaging tractography (DTIT) and functional MRI (fMRI) scans two weeks from presentation. Information on the acquisition and analysis of MR data are included in Appendix A. DTIT showed bilateral predominantly-uncrossed corticospinal tracts (CSTs), with very few decussating fibres tracts (Fig. 1). Her fMRI results, however, were divergent from those described in another patient with uncrossed corticospinal tracts.[1] Left ankle rotation and finger-tapping activated the ipsilateral and bilateral left motor areas respectively, while right-sided motor tasks unexpectedly activated contralateral primary motor areas, despite having predominantly-uncrossed right CSTs (Fig. 2). Mirror movements were not observed whilst performing the tasks. These findings suggested the presence of an aberrant interhemispheric connection superior to the region vulnerable to recurrent ischemia, conveying descending motor signal from the left motor areas to the predominantly-uncrossed right CST, decussating before and thus avoiding the symptomatic parenchyma supplied by the severely-stenotic left ICA. Transcranial magnetic stimulation (TMS) was performed to provide evidence of abnormal interhemispheric connections through the corpus callosum (Appendix A). Transcallosal conduction time (TCT), obtained by the difference between the onset latencies of the contralateral motor evoked potential and ipsilateral silent period, was 39.4 ms (ms) over the right and left lower limbs respectively [2–4]. This was approximately 3x of normal controls for that age group

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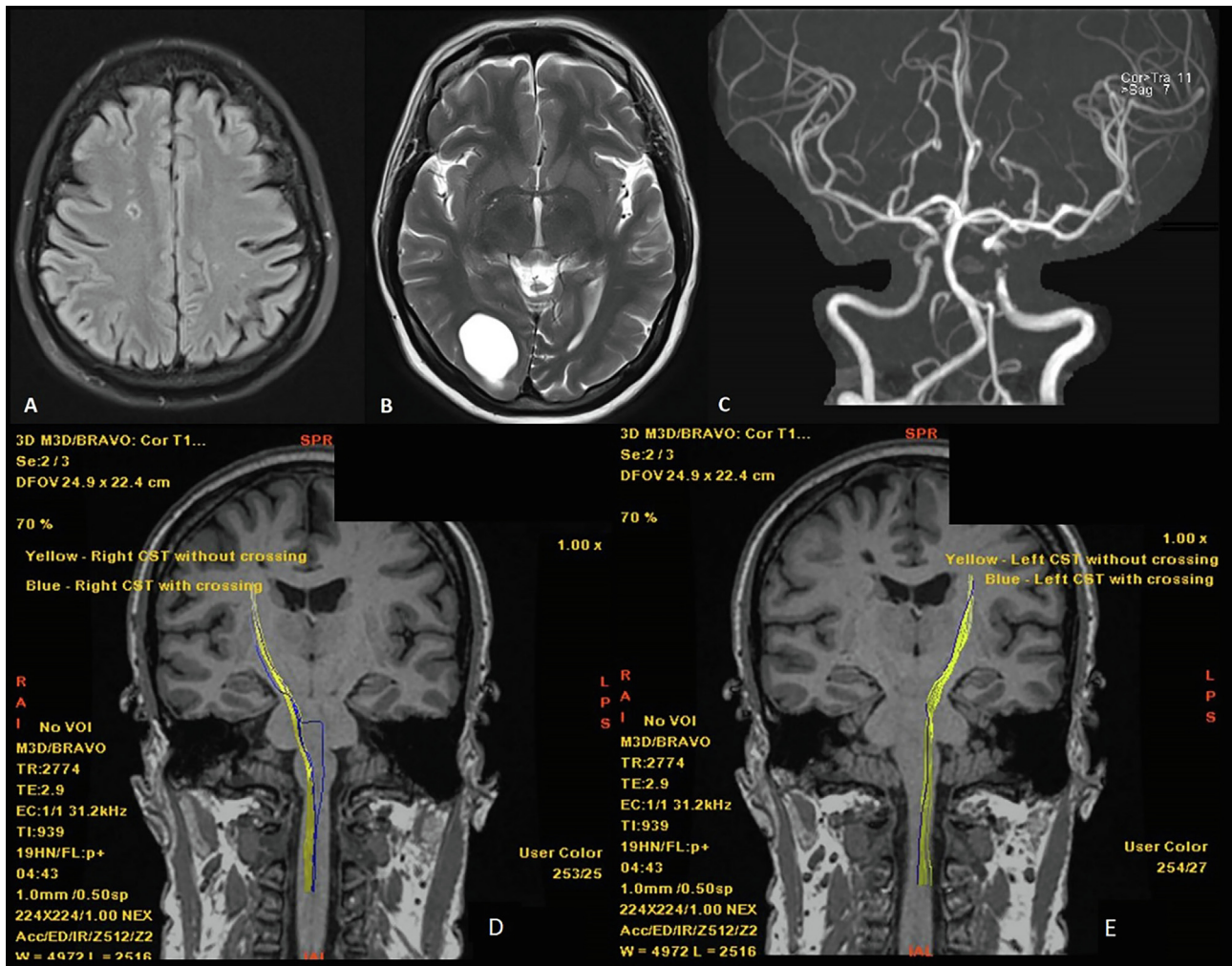


Fig. 1. MRI and MRA of the brain. A: T2/FLAIR: a chronic lacunar infarct is seen at the right centrum semiovale. B: T2: an arachnoid cyst is seen at the right occipital lobe, measuring $3.2 \times 2.1 \times 3.7$ cm. C: MRA showing the severe stenosis at the left cavernous ICA. D: DTIT of the right and E: left motor tracts, with majority of the CSTs descending ipsilaterally (yellow), while a few tracts decussate (blue).

[5]. These findings suggest the presence of abnormal interhemispheric conduction. These findings suggest the presence of abnormal interhemispheric conduction bidirectionally, and corroborates previous reports bimodal influence of the contralesional cortex after a cerebrovascular event [6]. Ipsilateral motor evoked potentials (MEPs) were elicited bilaterally, and the recordings of ISPs are shown in Fig. 4.

In all, DTIT findings reaffirmed our suspicion that the focal stenosis of the left ICA was responsible for her episodic ipsilateral hemiparesis through recurrent ischemia of the predominantly-uncrossed left CST, while fMRI and TMS were supportive of neuronal reorganization and abnormal interhemispheric connections. She was started on antiplatelet therapy, and remained asymptomatic when reviewed a year later.

2. Discussion

Ipsilateral hemiparesis due to supratentorial strokes is uncommon, and can be due to injuries to uncrossed CSTs [7,8]. Patients with uncrossed CSTs have been reported with congenital scoliosis, posterior fossa or brainstem malformations, and agenesis of corpus callosum [8,9–11]. Our patient’s uncrossed CSTs are likely the dominant descending motor pathways as reflected by the severity

of her weakness, and may be associated with her large occipital arachnoid cyst. Despite the presence of few decussating fibres at the caudal medulla, these are unlikely to be clinically significant in view of the paucity of right-sided symptoms during the attacks.

Her fMRI findings differed from our initial expectations. Terakawa et al. described the activation in the motor cortex ipsilateral to the finger movements, but not on the contralateral side, in a patient with uncrossed corticospinal tracts [1]. Unexpectedly, our patient showed activation of bilateral motor areas with left finger-tapping tasks, while right-sided tasks resulted in activating only the contralateral motor areas. A plausible explanation to our patient’s fMRI findings is the concomitant neuronal reorganization of the motor areas as a result of the previous right CS infarct, together with the presence of aberrant interhemispheric connections, the latter supported by our TMS findings.

Saada et al. identified five patients with ipsilateral hemiparesis (two right-sided, three left-sided) on a background of previous strokes, of which three demonstrated cortical reorganization on fMRI [8]. Song et al. described worsening ipsilateral left hemiparesis in two patients after acute left corona radiate (CR) infarctions [12]. Both had prior right CR strokes. fMRI in both patients demonstrated activation of the left sensorimotor cortex during right-handed tasks, and bilateral sensorimotor cortical activation during

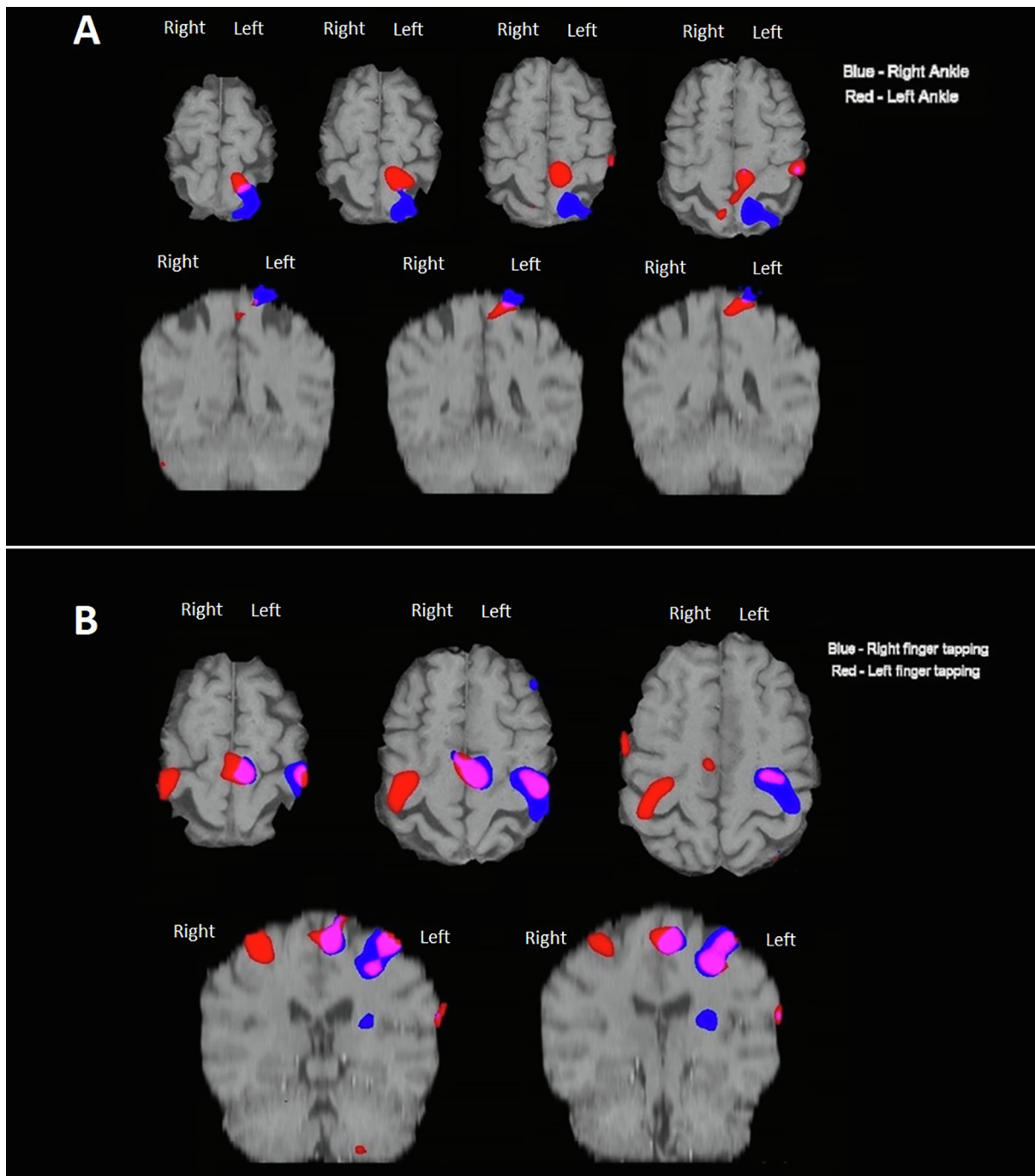


Fig. 2. A: fMRI showing the activation maps upon ankle motor tasks. Left ankle rotation resulted in the activation of ipsilateral left primary motor area, while right ankle rotation activated the contralateral (left) cortical motor areas. B: fMRI showing the activation maps upon finger tapping tasks. The left finger tapping resulted activated bilateral primary and supplementary motor areas, while the right finger tapping activated the contralateral (left) primary motor areas.

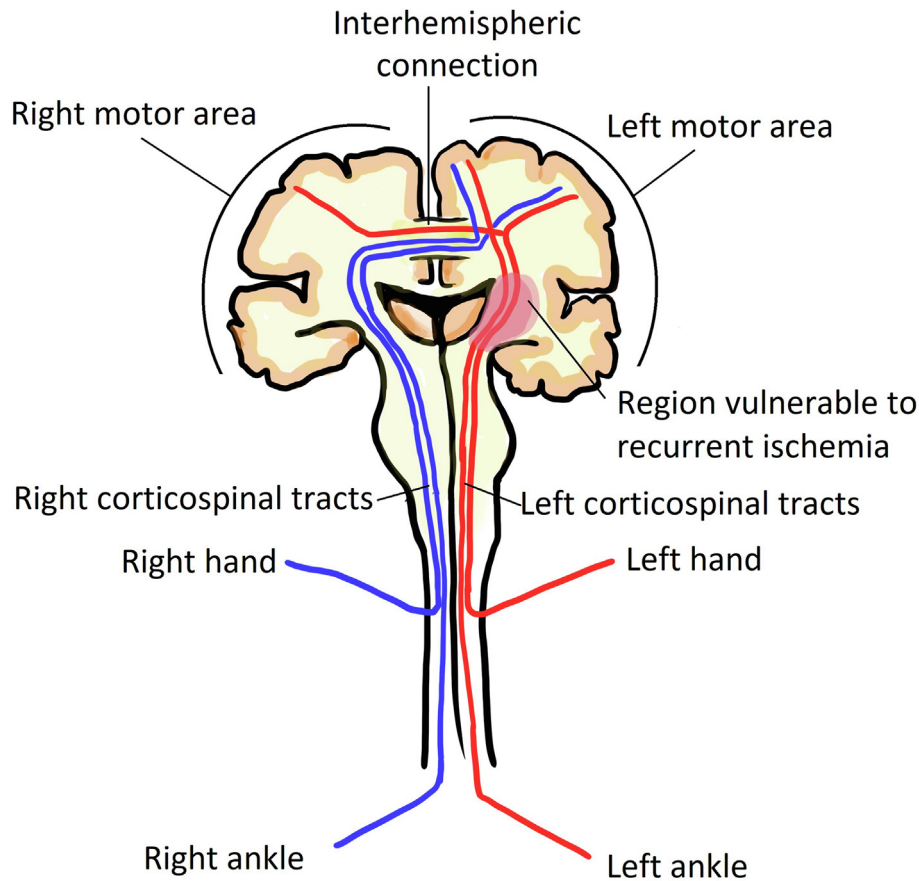


Fig. 3. This diagram illustrates the possible location of the aberrant interhemispheric connection or conduit, in relation to the traversing corticospinal tracts and the region vulnerable to recurrent ischemia from the severely-stenotic left ICA. This configuration correlates well with the clinical features and the DTIT and fMRI results.

left-handed tasks. Ago et al. reported a patient whose pre-existing left hemiparesis from a prior right-sided stroke worsened by a new left CR infarct [13]. fMRI demonstrated ipsilateral rather than a bilateral activation, with activation of left motor areas by gripping with the left hand, supportive of reorganization of the motor cortices. An old right CS infarct was incidentally detected on our patient’s MRI, while her fMRI findings were similar to the three aforementioned cases.

Reorganization of the motor areas can partly explain the activation patterns, but it cannot reconcile with our patient’s clinical deficits in the presence of predominantly-uncrossed CSTs, unless in the presence of an aberrant interhemispheric connection lying superior to the recurrently-ischemic region (Fig. 3). This interhemispheric ‘conduit’ can explain how right-sided tasks can result in activation of only the left motor areas, despite having predominantly-uncrossed CSTs. The few fibres decussating at the medulla are unlikely to play a major role in motor innervation, as recurrent ischemia failed to cause significant weakness over the right-sided limbs in our patient. The latter point also supports to the relatively superior location of this ‘conduit’, away from vulnerable parenchyma.

To our knowledge, this is the first reported case of ischemic ipsilateral hemiparesis in a patient with both predominantly-uncrossed CSTs and reorganization of the motor areas. When examined together, our patient’s DTIT, fMRI and TMS findings were supportive of an aberrant interhemispheric connection. Its exact location and nature cannot be answered presently by our clinico-radiological findings. What they do suggest, however, is the presence of a superiorly-placed interhemispheric ‘conduit’ providing

an alternative decussating pathway for the descending motor tracts, and may be an important partner to neuronal reorganization in the post-stroke recovery of patients with predominantly-uncrossed CSTs.

Funding

This case report did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

MR data acquisition

The patient underwent multiplexed sensitivity-encoding (MUSE) enabled diffusion tensor imaging (DTI) and functional MRI (fMRI) scans. All MRIs were performed using the GE 3 T MRI SIGNA Architect (GE Medical Systems, Singapore), with a 48-channel array head coil.

MUSE DTI was performed to reduce blurring and susceptibility induced distortions, and its parameters include: b values of 0 and 800 s/mm², number of directions = 30, repetition time (TR) = 737

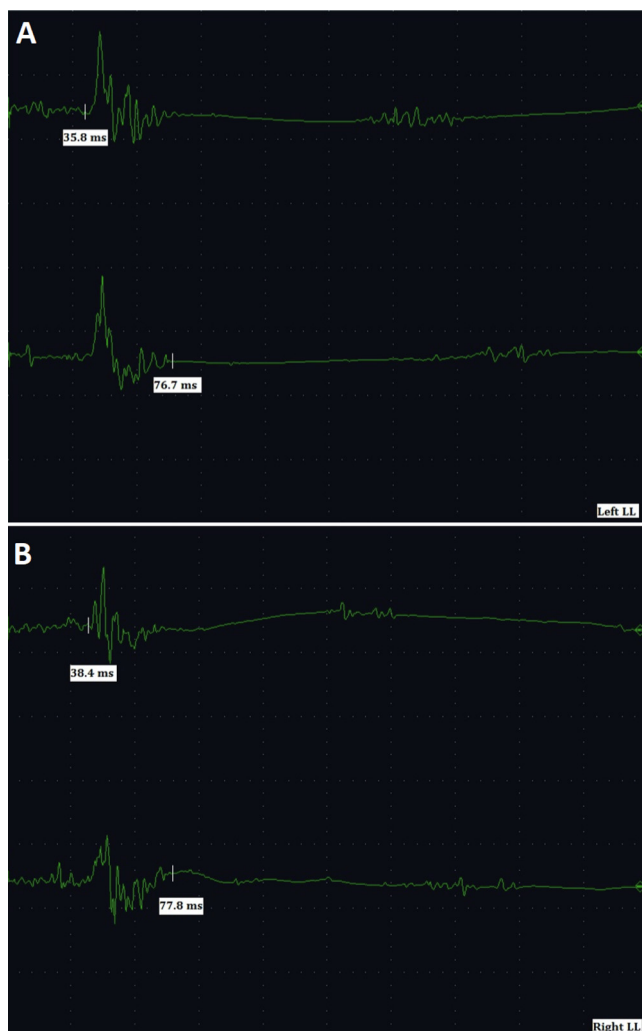


Fig. 4. Actual tracings of left and right lower limb recordings obtained after TMS respectively. The top trace (A) shows the contralateral MEP onset and bottom trace (B) shows the onset of ISP, appearing after the ipsilateral MEP. Marker values are indicated in milliseconds (ms).

Table A1
Corticospinal tracts with corresponding ROI seed points.

Corticospinal tract (CST)	ROI seed points
Right CST without crossing (Yellow)	1, 2 and 3
Right CST with crossing (Blue)	1, 4 and 3
Left CST without crossing (Yellow)	1, 4 and 5
Left CST with crossing (Blue)	1, 2 and 5

1 ms, echo time (TE) = 77.8 ms, slice thickness = 4 mm, and a resolution = 192 × 130.

Gradient-echo planar T2-weighted images with blood oxygen level-dependent (BOLD) contrast were acquired for fMRI measurements. The parameters include: TR = 3000 ms, TE = 30 ms, slice thickness = 4 mm, and pixel size = 3.8 × 3.8 mm. We performed block design fMRI paradigms alternating between rest

and activation tasks of both ankles and hands: ankle rotation tasks = individual ankle rotation; finger tapping task = abduction of the thumb against the sequential tapping of individual finger tips (i.e., index finger, followed in sequence by middle, ring and little fingers). Compliance to the performance of the tasks was enforced throughout the fMRI measurements. fMRI of the left ankle was performed thrice. An axial-T1 weighted spoiled gradient recalled echo (SPGR) scan was also obtained for DTI and fMRI post-processing purposes.

Control participants were first evaluated to determine the appearance of the corticospinal tracts, and the appropriate machine parameters and protocols.

MR data analysis

fMRI data were processed and evaluated using BrainWave PA 3.0 Ext.5. Pre-processing steps were done mainly co-registered the fMRI data to the T1-weighted (SPGR) volume scan, smoothing with a Gaussian spatial filter of full-width-half-maximum (FWHM) of 8 × 8 × 8 (mm) and motion correction⁴. Activation maps were generated using generalized linear model (GLM) analysis. The default Z scores were Z > 4.6 while the thresholding for individual task activation maps were as follows: right ankle (p = 0.010), left ankle (p = 0.001), right hand (p = 0.0001) and left hand (p = 0.012).

Tractography was performed using GE ReadyView DTI FiberTrak to seed and delineate the 3D corticospinal tracts. The fibre assignment is acquired by deterministic continuous tracking (FACT) algorithms, with maximum steps of 160, minimum fractional anisotropy (FA) value of 0.18, maximum attenuation coefficient (ADC) of 0.01, and maximum fibre angle of 360°. The ROI seed points used for fibre tracking of the right and left corticospinal tract (CST) were shown in Table A1 and Fig. A1.

Transcranial magnetic stimulation (TMS) data acquisition and analysis

TMS was performed with a Magstim round coil (Magstim, Whitland, United Kingdom), 12 cm in outer diameter, capable of generating a peak magnetic field of 2.2 T, in conjunction with a Magstim 200 unit. The coil was centered 2 cm to 3 cm anterior to the vertex to obtain maximal motor evoked potential (MEP) responses in the lower limb muscles. TMS was performed at 100% stimulator output, with the coil current direction in the clockwise and counter-clockwise directions for right and left motor cortex stimulation respectively. Surface recordings in the abductor hallucis muscles were obtained with Medtronic 9013S0241 (Medtronic, Skovlunde, Denmark) adhesive surface electrodes. Responses were amplified and filtered with a Dantec Keypoint machine (Dantec, Skovlunde, Denmark) with a band pass of 20–2000 Hz. During the course of each task, subjects performed maximal activation of the recording muscles. For all experiments, 10 stimulations for each side were performed and averaged.

The onset of ipsilateral silent period (ISP) in milliseconds (ms) was measured from the stimulus to a point where the signal of the averaged tonic electromyographic activity clearly fell under the mean amplitude of the electromyographic activity before the stimulus. Transcallosal conduction time (TCT) was defined as the difference between contralateral MEP onset latency and onset latency of the ISP.

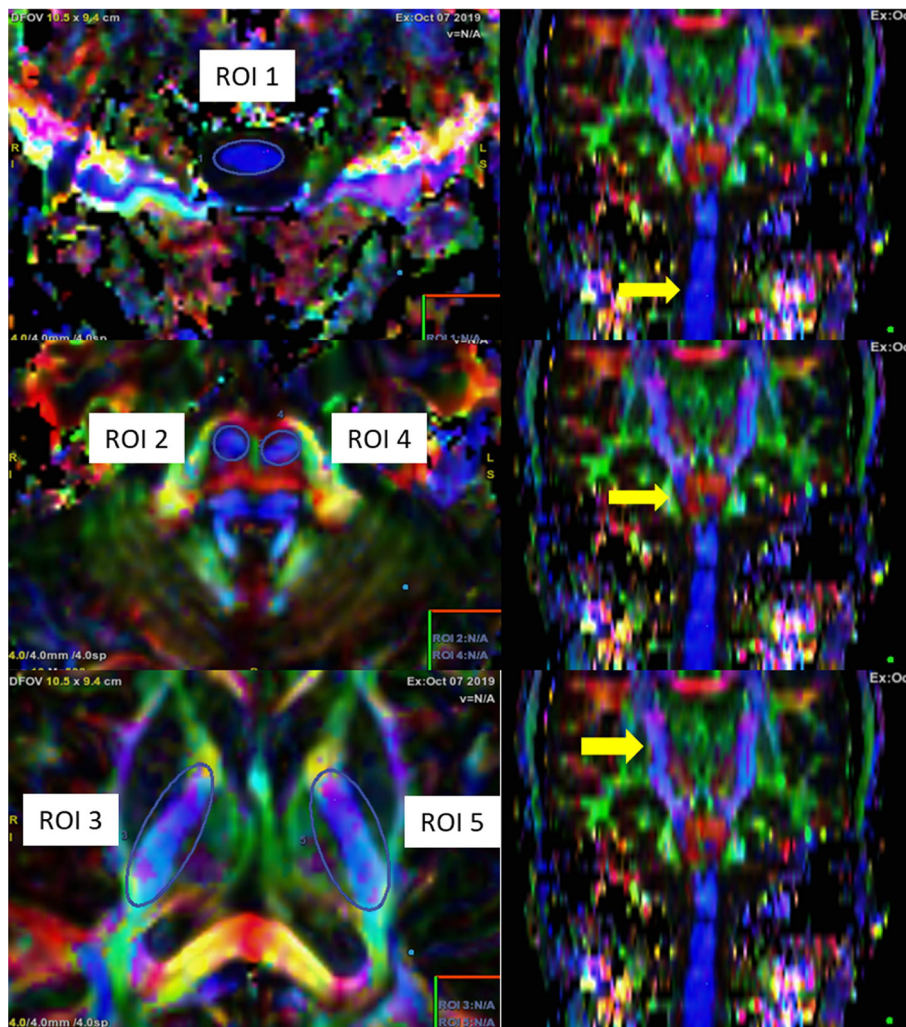


Fig. A1. ROI seed points for the corticospinal tracts. The diffusion tensor model is ideal only for describing a single fibre population within a given voxel, and alone does not have the ability to demonstrate crossing fibres, unless more complex models to quantify diffusion characteristics are developed or deployed.

References

[1] Terakawa H, Abe K, Nakamura M, Okazaki T, Obashi J, Yanagihara T. Ipsilateral hemiparesis after putaminal hem orrhage due to uncrossed pyramidal tract. *Neurology* 2000;54(9):1801–5.

[2] Meyer B-U, Rörich S, von Einsiedel HG, Kruggel F, Weindl A. Inhibitory and excitatory interhemispheric transfers between motor cortical areas in normal humans and patients with abnormalities of the corpus callosum. *Brain* 1995;118(2):429–40.

[3] Meyer B-U, Rörich S, Woiciechowsky C. Topography of fibers in the human corpus callosum mediating interhemispheric inhibition between the motor cortices. *Ann Neurol* 1998;43(3):360–9.

[4] Schmierer K, Niehaus RS, Meyer BU. Conduction deficits of callosal fibers in early multiple sclerosis. *J Neurol Neurosurg Psychiatry* 2000;68:633–8.

[5] Lo YL, Fook-Chong S. A transcranial magnetic stimulation study of the ipsilateral silent period in lower limb muscles. *Neurosci Lett* 2004;368(3):337–40.

[6] Lin Y-L, Potter-Baker KA, Cunningham DA, Li M, Sankarasubramanian V, Lee J, et al. Stratifying chronic stroke patients based on the influence of contralateral motor cortices: An inter-hemispheric inhibition study. *Clin Neurophysiol* 2020;131(10):2516–25.

[7] Inatomi Y, Nakajima M, Yonehara T, et al. Ipsilateral hemiparesis in ischemic stroke patients. *Acta Neurol Scand* 2016;00:1–10.

[8] Saada F, Antonios N. Ipsilateral Hemiparesis in Ischemic and Hemorrhagic Stroke. *Eur Neurol* 2014;71:25–31.

[9] Lager RL. Failure of pyramidal tract decussation in the Dandy-Walker syndrome. Report of two cases *J Neurosurg* 1979;50:383–7.

[10] Donkelaar HJ, Lammens M, Wesseling P, Hori A, Keyser A, Rotteveel J. Development and malformations of the human pyramidal tract. *J Neurol* 2004;251(12):1429–42.

[11] Ng ASL, Sitoh Y-Y, Zhao Yi, Teng EWL, Tan EK, Tan LCS. Ipsilateral stroke in a patient with horizontal gaze palsy with progressive scoliosis and a subcortical infarct. *Stroke* 2011;42(1). <https://doi.org/10.1161/STROKEAHA.110.591271>.

[12] Song Y-M, Lee J-Y, Park J-M, Yoon B-W, Roh J-K. Ipsilateral hemiparesis caused by a corona radiata infarct after a previous stroke on the opposite side. *Arch Neurol* 2005;62(5):809. <https://doi.org/10.1001/archneur.62.5.809>.

[13] Ago T, Kitazono T, Ooboshi H, et al. Deterioration of pre-existing hemiparesis brought about by subsequent ipsilateral lacunar infarction. *J Neurol Neurosurg Psychiatry* 2003;74:1152–3.