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Clinical Case Report

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The Ascending Reticular Activating System in a Patient With Severe Injury of the Cerebral Cortex

A Case Report

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Abstract: We reported on the ascending reticular activating system (ARAS) finding of a patient in whom severe injury of the cerebral cortex was detected following a hypoxic-ischemic brain injury (HIBI).

A 67-year-old female patient who suffered from HIBI induced by cardiac arrest after surgery for lumbar disc herniation underwent cardiopulmonary resuscitation approximately 20 to 30 minutes after cardiac arrest. The patient exhibited impaired alertness, with a Glasgow Coma Scale (GCS) score of 4 (eye opening: 2, best verbal response: 1, and best motor response: 1). Approximately 3 years after onset, she began to whimper sometimes and showed improved consciousness, with a GCS score of 10 (eye opening: 4, best verbal response: 2, and best motor response: 4) and Coma Recovery Scale-Revised score of 9 (auditory function: 1, visual function: 1, motor function: 2, verbal function: 2, communication: 1, and arousal: 2).

Results of diffusion tensor tractography for the upper connectivity of the ARAS showed decreased neural connectivity to each cerebral cortex in both hemispheres. The right lower ARAS between the pontine reticular formation and the thalamic intralaminar nuclei (ILN) was thinner compared with the left side.

Severe injury of the upper portion of the ARAS between the thalamic ILN and cerebral cortex was demonstrated in a patient with some level of consciousness.

(*Medicine* 94(42):e1838)

Abbreviations: ARAS = Ascending reticular activating system, DTT = Diffusion tensor tractography, GCS = Glasgow coma scale, HIBI = Hypoxic-ischemic brain injury, ILN = Intralaminar nucleus, ROI = Region of interest.

Editor: Faik Ilik.
Received: June 4, 2015; revised: September 22, 2015; accepted: September 23, 2015.
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This work was supported by the National Research Foundation(NRF) of Korea Grant funded by the Korean Government(MSIP) (2015R1A2A2A01004073).
The authors report no conflicts of interest.

ISSN: 0025-7974
DOI: 10.1097/MD.0000000000001838

INTRODUCTION

Consciousness is mainly controlled by the ascending reticular activating system (ARAS). Diffusion tensor tractography (DTT), which is derived from diffusion tensor imaging (DTI), is one of the most remarkable recent advances in neuroimaging.[1] Water diffuses preferentially in a direction parallel to the axon's longitudinal axis; in contrast, diffusion is restricted in the perpendicular axis.[1] This phenomenon can be represented mathematically by the diffusion tensor and the diffusion tensors of the cerebral white matter can be reconstructed to track 3-dimentional macroscopic fiber orientation in the brain.[1] DTT has enabled 3-dimensional reconstruction and estimation of the ARAS in the human brain.[2–6] Recent studies have reported on the state of the ARAS in various brain pathologies including traumatic brain injury, intracerebral hemorrhage, and hypoxic-ischemic brain injury (HIBI).[2,3,7–10]

Many studies have reported on patients with severe injury of the whole cerebral cortex, such as hydranencephaly or hemihydranencepahly, who have some level of consciousness.[11–14] However, no study on the ARAS finding of these patients has been reported so far.

In this study, using DTT, we reported on the ARAS finding of a patient who showed severe injury of the cerebral cortex following a HIBI.

CASE REPORT

A 67-year-old female patient who suffered from HIBI induced by cardiac arrest after surgery for lumbar disc herniation underwent cardiopulmonary resuscitation approximately 20 to 30 minutes after cardiac arrest. After 3 months from onset, she was admitted to the rehabilitation department of our university hospital for rehabilitation. The patient exhibited impaired alertness, with a Glasgow Coma Scale (GCS) score of 4 (eye opening: 2, best verbal response: 1, and best motor response: 1).[15] Diffusion-weighted brain MR images at 4 days after onset showed increased intensities in the whole cerebral cortex (Fig. 1A). In addition, T2-weighted brain MR images at 3 years after onset showed leukomalactic lesions in the whole cerebral cortex (Fig. 1B). She underwent comprehensive rehabilitative therapy, which included neurotropic drugs, physical therapy, and occupational therapy. At approximately 8 months after onset, she began to open her eyes in response to calling. Approximately 2 years after onset, she was able to close her eyes in response to a question and began to move the toes on both feet (flexion-extension 20ï~ï30′) after voiding or defecating in a diaper until a caregiver changed the diaper. Approximately 3 years after onset, she began to whimper sometimes and showed improved consciousness, with a GCS score of 10 (eye opening: 4, best verbal response: 2, and best motor response: 4) and Coma Recovery Scale-Revised score of 9 (auditory function: 1, visual function: 1, motor function: 2, verbal function: 2,

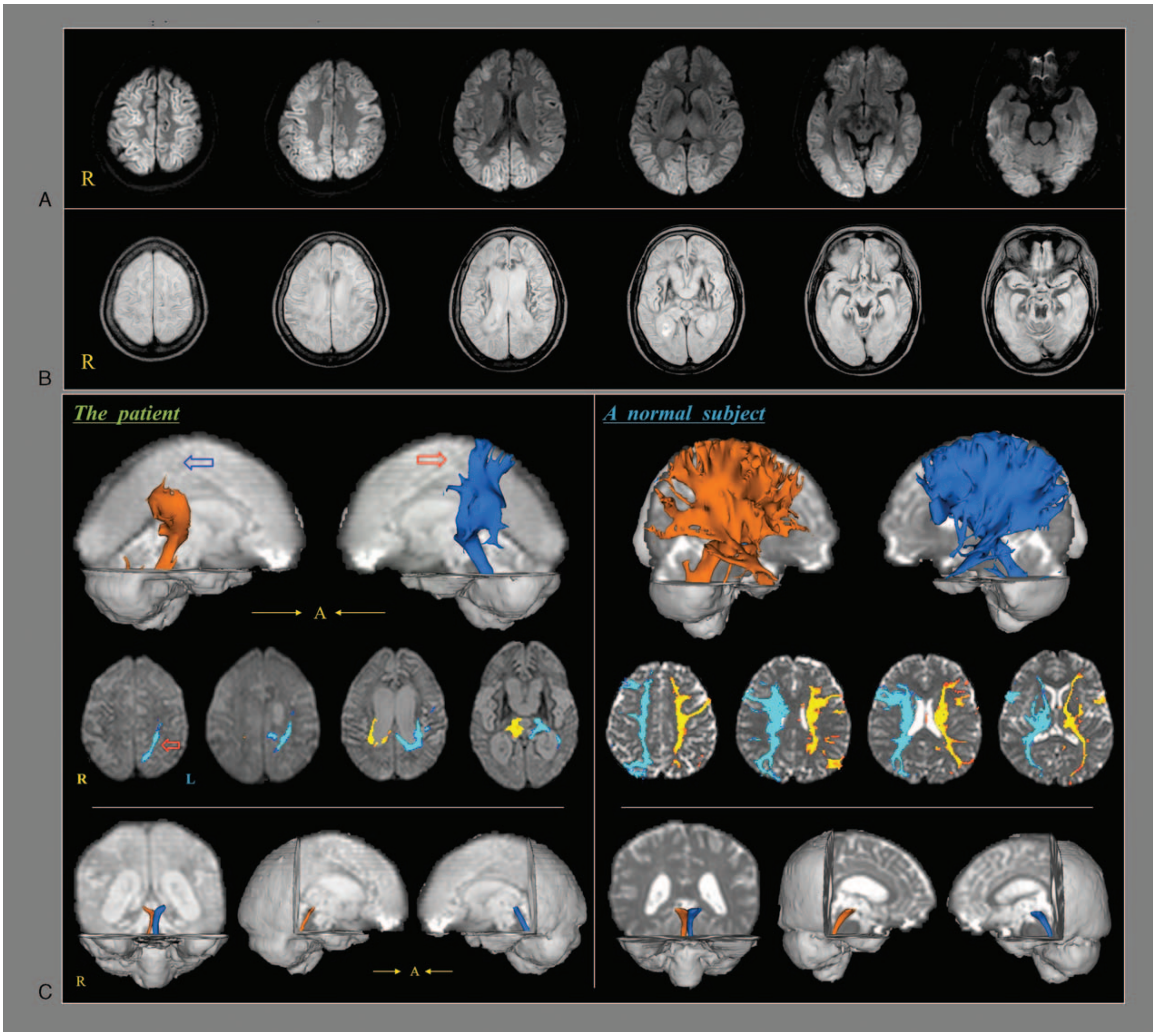

FIGURE 1. (A) Diffusion-weighted brain MR images at 4 days after onset show increased intensities in the whole cerebral cortex. (B) T2-weighted brain MR images at 3 years after onset show leukomalactic lesions in the whole cerebral cortex. (C) Results of diffusion tensor tractography for the upper connectivity of the ascending reticular activating system (ARAS). Results of diffusion tensor tractography for the upper connectivity of the ARAS showed decreased neural connectivity to each cerebral cortex in both hemispheres: the right hemisphere—no neural fibers reached the cerebral cortex (blue arrow), and the left hemisphere—some neural fibers were connected to the parietal cortex (red arrow). The right lower ARAS between the pontine reticular formation and the thalamic intralaminar nuclei was thinner compared with the left side of the patient and those of a normal subject (68-year-old female).

communication: 1, and arousal: 2).[16] The patient's daughter provided signed, informed consent, and Yeungnam university hospital institutional review board approved the study protocol.

DTI

DTI data were acquired at approximately 3 years after onset using a 6-channel head coil on a 1.5-T Philips Gyroscan Intera (Philips, Best, Netherlands) with single-shot echo-planar imaging. For each of the 32 noncollinear diffusion sensitizing gradients, 67 contiguous slices were acquired parallel to the anterior commissure-posterior commissure line. Imaging parameters were as follows: acquisition matrix = 96 × 96; reconstructed matrix = 192 × 192; field of view = 240 × 240 mm^2; TR = 10,726 ms; TE = 76 ms; b = 1000 s/mm^2; NEX = 1; and a slice thickness of 2.5 mm with no gap (acquired isotropic voxel size 1.3 × 1.3 × 2.5 mm^3). Analysis of DTI data was achieved using the Oxford Centre for Functional Magnetic Resonance Imaging of the Brain Software Library (FSL; streamline samples: 5000, step length: 0.5 mm, and curvature thresholds: 0.2).

For analysis of the lower ARAS, the seed region of interest (ROI) was placed at the reticular formation of the pons at the level of the trigeminal nerve entry zone and the target ROI was placed at the intralaminar nuclei of the thalamus at the level of the commissural plane.[3] In analysis of the connectivity of the intralaminar nucleus (ILN) of the thalamus, the seed ROI was placed at the ILN of the thalamus at the level of the intercommissural plane between the anterior and posterior commissures.[5] Of 5000 samples generated from the seed voxel, results for contact were visualized at a threshold for the ARAS of a minimum of 5 and for connectivity of the intralaminar nucleus of 30 streamlined through each voxel for analysis.

Results of DTT for the upper connectivity of the ARAS showed decreased neural connectivity to each cerebral cortex in both hemispheres: the right hemisphere (no neural fibers reached the cerebral cortex) and the left hemisphere (only some neural fibers were connected to the parietal cortex) (Fig. 1C). The right lower ARAS between the pontine reticular formation and the thalamic ILN was thinner compared with the left side.

DISCUSSION

In the current study, using DTT, the ARAS was evaluated in a patient with severe injury of the cerebral cortex following a HIBI. The ARAS was divided into 2 portions: the lower ARAS between the pontine reticular formation and the thalamic ILN: 3-dimensional reconstruction and the upper ARAS: the neural connectivity of the thalamic ILN to the cerebral cortex. We found that only some neural fibers were connected to the left parietal cortex, no neural fibers were connected to the other fronto-parieto-occipital cortex, and the right lower ARAS was thinner. These findings appear to suggest severe injury of the upper ARAS between the thalamic ILN and cerebral cortex, and mild injury of the right lower ARAS between the pontine reticular formation and the thalamic ILN.

Previous studies have demonstrated that patients with near-total or total absence of the cerebral cortex due to hydranencephaly or hemihydranencepahly had some level of consciousness such as person recognition, social interaction, funtional vision, muscial preferences, smiling at someone, appropriate affective response, and goal-directed motor behavior.[11–14] Therefore, Merker[13] suggested that the thalamocortical system is not an essential system for consciousness, but the midbrain reticular system is responsible for consciousness. Rearding our patient, the patient was able to perform goal-directed behavior (close her eyes in response to a question and move the toes on both feet after voiding or defecating in a diaper until a caregiver changed the diaper) and express her emotion (whimpering). We believe that our patient also had some level of consciousness, even though injury of the whole cerebral cortex was observed on the brain MR images and DTT showed that only some neural connectivity to the left parietal lobe was spared.

In conclusion, severe injury of the upper portion of the ARAS between the thalamic ILN and cerebral cortex was demonstrated in a patient with some level of consciousness. We believe that evaluation of the ARAS using DTT would be useful in elucidating the state of the ARAS. This is the first DTT study to demonstrate the state of the ARAS in a patient with severe injury of the whole cerebral cortex. However, limitations of DTT should be considered. First, DTT technique is operator-dependent.[17] Second, regions of fiber complexity and crossing can prevent full reflection of the underlying fiber architecture; therefore, DTT may underestimate the fiber tracts[1]

ACKNOWLEDGMENTS

None.

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