Technology Review
AN MIT ENTERPRISE

Wednesday, January 24, 2007

Part II: Raising Consciousness

Some seemingly unconscious patients have startlingly complex brain activity. What does that mean about their potential for recovery? And what can it tell us about the nature of consciousness?

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Lesions of Consciousness

We'll probably never know whether Terry Wallis also had some awareness before his awakening. But a type of brain imaging known as diffusion tensor imaging (DTI) has given researchers hints about how his brain has changed since.

DTI is a variation of MRI that offers an unprecedented view of the brain's wiring system--the long, thin tails of neurons that carry electrical signals between different regions. Wallis's first DTI scan, recorded eight months after his first word, revealed that he had profound brain damage. But scientists also discovered possible signs that new neural connections had sprouted between brain structures. In particular, a large area in the back of his brain appeared to have more neural fibers than normal, all oriented in the same direction. The area encompassed by these new fibers included a part of the brain known as the precuneus, which is highly active during conscious wakefulness but less active during sleep or anesthesia.

Eighteen months after that scan, Wallis was doing even better. He could move his previously paralyzed legs, an improvement "as unexpected as him recovering speech," says Schiff. When the researchers imaged his brain a second time, they found that the unusual area in the back had normalized, while a region involved in regulating movement seemed to have grown more connected. The findings were published last year in the *Journal of Clinical Investigation*.

The researchers can't yet be sure that the changes they saw in the brain images really do indicate the growth of new neuronal connections, nor that those changes sparked Wallis's recovery. "Why did he emerge? None of us can answer this," says Hirsch. "But it

suggests a biological underpinning to recovery."

Brain imaging might eventually be used as a diagnostic tool to help spot those who are most likely to recover. "We need to develop better ways to model and measure the emergence to consciousness and collect enough data so that we can make statistical predictions for recovery," says Schiff. However, identifying the telltale changes that predict awakening promises to be difficult. Schiff and Hirsch have scanned more than a dozen other patients in addition to Wallis, including several who have awakened, and they have yet to find specific patterns or changes in brain activity that might signal that a patient is improving. But they're still looking--at whether the network hubs of the brain are active, for example, or whether activity in different brain areas is in sync. "We think of patients with traumatic brain injury as patients with lesions of consciousness," says Hirsch. She hypothesizes that consciousness arises from a network of connections rather than in a specific location in the brain.

The brain is constantly processing information: sights and sounds are recorded and synthesized in different parts of the brain, then fused together in other areas, creating a cohesive picture of the outside world. And early evidence indicates a link between consciousness and the ability to integrate information. In a study of 60 patients in the vegetative state, Laureys found that the seven patients who later awakened recovered brain metabolism in regions that connect the cortex with the thalamus, a relay center in the brain.

Injury to the brain may tear the nerve fibers that relay messages between different regions, impeding the integration process. Similarly, Schiff believes that the circuits left intact in minimally conscious and vegetative patients may communicate erratically, making it difficult for the brain to coördinate complex tasks involving multiple brain areas. Patients with impaired consciousness also exhibit low levels of neural activity, Schiff says; their brains may take a stab at a particular task, generating the brief appearance of responsiveness, but then peter out. A patient's occasional moments of clarity, then, might come from brief spurts of synchronized activity. "Some patients may harbor the capacity for functional recovery, but it depends on recruiting circuit-level neuronal responses to sustain a state like that of the brain working normally," Schiff says. Emotional events, such as a sister's description of childhood memories, may do a better job of activating those circuits, which could explain why emotional stories seem to trigger the strongest responses.

Understanding what causes impairments in consciousness could ultimately shed light on a larger puzzle: what allows a healthy person to be aware of self and surroundings? "I

think that a detailed understanding of the necessary and sufficient conditions for the recovery of consciousness will provide immensely important insights into the fundamental nature of the human conscious state," says Schiff.

Abandoned

Schiff's ultimate goal, of course, is to spark awakenings like that of Terry Wallis in other minimally conscious patients. At a neuroscience meeting last October, he presented preliminary evidence that electrically stimulating the thalamus, which sends sensory information to the cerebral cortex, might help patients recover consciousness. Schiff and his team used deep brain stimulation--a therapy used to treat Parkinson's disease, where an electrode is implanted in the brain--to stimulate thalamic neurons in a 38-year-old minimally conscious patient who had suffered a severe traumatic brain injury six years before. They found that when the neurons were stimulated, the patient was more responsive and coördinated, even able to eat a meal with some independence.

Though Schiff is reluctant to talk about his group's findings before they are published in a peer-reviewed paper, he and other neurologists are clearly excited about them. "This is a very interesting and important observation," says James Bernat, a neurologist at Dartmouth Medical School, who adds that Schiff's result is particularly noteworthy because the patient had been in a minimally conscious state for so long. Previous studies of deep brain stimulation, carried out mostly in Japan, have involved recently injured patients, who might have improved anyway.

To prove the efficacy of deep brain stimulation in treating consciousness disorders, and to determine just which patients it might help, other researchers will need to duplicate Schiff's success. But that's a tall order. Research on minimally conscious and vegetative patients presents enormous obstacles--the logistics of transporting patients from long-term-care facilities to imaging labs, the ethical and legal issues involved in testing people who cannot give informed consent, and the technical challenge of scanning patients who may move unpredictably and may not be able to comprehend instructions to stay still.

But the biggest barrier to larger studies is funding. Terry Wallis is one of the most remarkable recovery cases Schiff has ever seen. And yet he's examined him just twice: first when a British television station flew Wallis and his family from Arkansas to New York, where Schiff and collaborators could scan his brain; and then when the producers of an HBO documentary paid Wallis's fare to New York 18 months later, so that scientists could assess the changes that had taken place since the first scan.

One might expect that some of the exciting research with minimally conscious patients in the last two years would bring more money to the field, but that has yet to happen. In early November, Schiff received disappointing news: the National Institutes of Health, the primary biomedical funding agency in the United States, had declined to fund larger studies of the diagnostic methods he and others have been developing. He says that while some grant reviewers are excited by the recent findings, others are reluctant to spend money on a group of patients they see as beyond hope. "I think it shows a discriminatory bias against this patient pool," says Schiff.

Neurologists studying disorders of consciousness say fatalism about their patients' prospects extends far beyond the walls of funding organizations. Wallis's family, for example, petitioned for a neurologist annually for 19 years without success. And Schiff says the families of patients enrolled in his studies often thank him for being interested at all. "Their uniform experience is that no one cares," he says. "They are completely abandoned by people who would otherwise have taken care of them."

If Schiff and others are right, this population of abandoned patients includes many people aware of their surroundings. And Wallis's recovery serves as an example of just how much some of these patients might be able to improve if they can be gently prodded back to the world of full consciousness. As Wallis works diligently on his rehab exercises, Schiff continues his dogged search for clues as to how to spark such a recovery in others, coming ever closer to understanding the mysteries of consciousness.

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