

Reviving Consciousness

Direct stimulation of the arousal centers in patients may restore awareness

BY CHRISTOF KOCH



MOST SCHOLARS concerned with the material basis of consciousness are cortical chauvinists. They focus on the two cortical hemispheres that crown the brain. It is here that perception, action, memory, thought and consciousness are said to have their seat.

There is no question that the great specificity of any one conscious perceptual experience—such as the throbbing pain of the socket following extraction of the lower right wisdom tooth, the feeling of familiarity in déjà vu, the aha experience of sudden understanding, the azure blue of a high mountain vista, the despair at reading about one more suicide bombing—is mediated by coalitions of synchronized cortical nerve cells and their associated targets in the satellites of the cortex, thalamus, amygdala, claustrum and basal ganglia. Groups of cortical neurons are the elements that construct the content of each particular rich and vivid experience. Yet content can be provided only if the basic infrastructure to represent and process this content is intact. And it is here that the less glamorous regions of the brain, down in the catacombs, come in.

When Consciousness Leaves

It is a general observation in neurology that injury to large chunks of cortical tissue, particularly of the so-called silent frontal lobes, can lead to a loss of specific conscious content but without any massive impairment in the victim's behavior. The patient might be unable to see in color or perhaps cannot recognize familiar faces but otherwise copes fine

in daily life. But destruction of tissue the size of a sugar cube in the brain stem and in parts of the thalamus, especially if they occur simultaneously on the left and right sides, may leave the patient comatose, stuporous or otherwise unable to function. A car accident, a drug or alcohol overdose, a drive-by shooting, a near drowning, a stroke—all these



Can we help severely brain-injured patients regain some higher-level functionality?

events can cause consciousness to flee permanently.

A case in point was Terri Schiavo. On life support for 15 years until her court-ordered death, she was in a permanent vegetative state (VS), with a flat EEG (electroencephalograph) reading, indicative that her cortex had stopped working. Such individuals show no overt behavioral responses that rise above the level of brain stem-mediated reflexes. Two-way signaling, say, a nod in response to the question "Are you in pain?" is not possible. Less severe brain damage leads to a minimally conscious state (MCS). Although patients are still disabled, confined to bed and on a feed-

ing tube, some sort of communication, albeit erratic and often inconsistent, occurs. Patients may be able to gesture or follow with their eyes. Awareness of their own condition and their environment is impaired and intermittent.

VS and MCS are not rare. In the U.S., up to a quarter of a million people in hospices and nursing homes hover for years in this limbo, a steep medical and emotional burden for many. This scourge is the paradoxical outcome of progress in critical care technology—mechanical ventilators, medevac helicopters, emergency room nurses and physicians, and the modern pharmaceutical cornucopia. With these tools, victims can be plucked back from the edge of death. This fate is a blessing for most, but it may be a curse for some.

Given the large number of affected individuals, you might think there is a large-scale, federally coordinated research effort under way, fostering techniques to rehabilitate the damaged brain. But you would be mistaken. For a variety of reasons, society at large has neglected this population.

Sparking a Return

Now a few hardy pioneers are finding innovative ways to help. Their technology of choice is deep-brain stimulation (DBS). The method has been much in the public eye as a way to ameliorate the symptoms of Parkinson's disease. Electrodes are implanted into a region just below the thalamus, the quail-egg-shaped structure in the center of the brain. When

CHRISTOF KOCH (Koch); GETTY IMAGES (comatose patient)

Patients can be plucked back from **the edge of death**—
a blessing for most, but a curse for some.

the electric current is turned on, the rigor and tremors of this movement disorder disappear instantly.

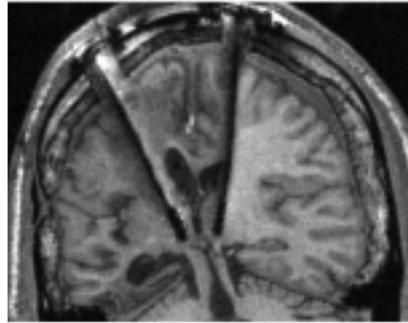
Over the past 15 years neurosurgeon Takamitsu Yamamoto and his colleagues at the Nihon University School of Medicine in Tokyo stimulated parts of the intralaminar nuclei (ILN) of the thalamus in VS and MCS patients. These regions were targeted because they are involved in producing arousal and in controlling widespread activity throughout the cortex. Indeed, according to the late neurosurgeon Joseph Bogen of the University of Southern California, the ILN is the one structure absolutely essential to consciousness.

Patients react immediately when the ILN is stimulated in this manner: they open their eyes, their pupils dilate, they make meaningless sounds, their blood pressure increases and their EEG activity desynchronizes. This arousal reaction by itself is not of therapeutic utility and does not predict recovery. But the long-term effect of such stimulation was encouraging: eight of 21 patients transitioned from the unresponsive VS to the more communicative MCS condition, and the five MCS patients who were stimulated emerged from their bedridden state, with four of them able to enjoy life back at home. Because Yamamoto exclusively targeted therapy to between three and six months after the patient's injury, however, most likely at least some of these patients would have recovered spontaneously, even without intervention.

Furthermore, it is doubtful that any type of DBS could be beneficial to the most severely affected patients, such as those in permanent VS. As a historical note, Schiavo was enrolled in one of these earlier brain-stimulation trials, but to no avail.

A recent judicious case study of a single MCS patient, however, directly demonstrated the usefulness of DBS. It was carried out by a multi-institutional team

of neurologists, neurosurgeons, neuroscientists and an ethicist assembled by Nicholas D. Schiff of the Weill Cornell Medical College in New York City, Joseph T. Giacino and Kathleen Kalmar of the JFK Johnson Rehabilitation Institute in Edison, N.J., and the Cleveland Clinic in



MRI image shows two electrodes in a patient's thalamus, through which doctors apply direct brain stimulation. The technique has restored greater awareness and the ability to eat and talk to one severely brain-injured patient in a minimally conscious state.

Ohio. The 38-year-old patient suffered severe brain trauma from an assault. After some initial improvement, his condition stabilized and did not change substantially over the next six years. The individual had the characteristic pattern of MCS: minimum motor control, mainly voluntary eye movements, and, infrequently, single words or other vocalizations; he could not even eat by mouth.

After implanting two electrodes in the anterior parts of the left and right ILN of the patient's thalami and after a two-month postoperative recovery period, the patient went through 11 months of on-and-off DBS therapy. The outcome

was a remarkable improvement in the man's awareness and motor control. When the DBS is turned on, the patient can make hand and arm movements and can chew and swallow his own food, a major step in improving his quality of life. Most dramatically, he can communicate via gestures, words and, at times, short sentences. Some of these activities depend on ongoing electrical stimulation, implying a direct causal effect of DBS on cognitive and motor skills. Furthermore, the almost one-year-long DBS therapy has ameliorated the overall functionality of the patient's brain because some of the beneficial effects persist even when DBS is turned off. In other words, the treatment has both sustained short-term benefits as well as slowly accumulated long-term carryover effects.

One successful intervention is not a proven therapy, nor a cure for MCS, as Schiff and his colleagues caution. MCS is a very diverse syndrome, and whether any improvement occurs, and on what time-scale, will depend on a host of factors, such as severity and distribution of the injury, overall condition of the patient, and so on. But if the improvement is replicated, it shows that advances in the basic neurosciences, combined with the appropriate prosthetic technology, might restore motor functions and the mechanisms supporting awareness in the brain. **M**

CHRISTOF KOCH is Lois and Victor Troendle Professor of Cognitive and Behavioral Biology at the California Institute of Technology. He serves on *Scientific American Mind's* board of advisers.

(Further Reading)

- ◆ **Deep Brain Stimulation Therapy for the Vegetative State.** Takamitsu Yamamoto and Yoichi Katayama in *Neuropsychological Rehabilitation*, Vol. 15, Nos. 3–4, pages 406–413; 2005.
- ◆ **Behavioural Improvements with Thalamic Stimulation after Severe Traumatic Brain Injury.** Nicholas D. Schiff et al. in *Nature*, Vol. 448, pages 600–604; August 2, 2007.
- ◆ **Deep Brain Stimulation, Neuroethics, and the Minimally Conscious State.** Nicholas D. Schiff, Joseph T. Giacino and Joseph J. Fins in *Archives of Neurology*, Vol. 66, pages 697–702; June 2009.

FROM "BEHAVIOURAL IMPROVEMENTS WITH THALAMIC STIMULATION AFTER SEVERE TRAUMATIC BRAIN INJURY," BY NICHOLAS D. SCHIFF ET AL., IN *NATURE*, VOL. 448, AUGUST 2, 2007