OUR UNDERSTANDING of the basic effects of brain damage in stroke victims has changed greatly in the last few years. It is imperative for those who treat stroke victims to appreciate what has happened to their patients in the light of modern concepts of physiology. This issue of Current Concepts reviews some of the newer physiological concepts that underlie the behavioral changes manifested by stroke patients and the concepts which are utilized in present-day rehabilitation efforts.

To appreciate what happens to the person who has sustained brain damage from a cerebral vascular accident (CVA), it is first necessary to conceptualize the dynamic functioning of the brain. For most of us, this means discarding the simple schematic diagrams and functional maps which were the standard in neuroanatomical teaching for almost a hundred years. The nineteenth century anatomist treated the brain in much the same way as any other organ and described various readily apparent subdivisions (lobes, medulla, pons, ganglia, etc.). Early neurophysiologists attempted to ascribe function to these identifiable segments. The late nineteenth and early twentieth century saw a great deal of neurophysiological research, much of it dubious and not reproducible, carried out primarily on lower mammals and occasionally primates. Most of this work would not have passed muster by today's standards because of inadequate understanding of the effects of electrical stimulation and of failure to take into account a host of unforeseen variables such as intensity of stimulation, degree of anesthesia, lack of reproducibility, and identification of areas stimulated. As a result, in keeping with the mechanistic philosophy of the times, simplistic cortical maps and diagrams of pathways led to a highly simplistic view of the human brain, which was widely taught up until the most recent times.

One of these early concepts which is still perpetuated in many textbooks is the well-known cortical map illustrating numerous areas of the brain as having specific and discrete functions separate and distinct from other portions of the brain. It is often forgotten that the various researchers producing cortical maps frequently did not agree and, even worse, that studies done on lower primates were simply transposed over the picture of a human brain and considered to have been "homologized for man."

This schematic and mechanistic view of the brain produced in many clinicians' minds what might be called the "apple pie concept" of brain damage. In this way of thinking, occlusion of a specific artery results in damage that is likened to removing a slice of pie from an otherwise intact brain with the clinical picture dependent on the functions subserved by that particular slice of the brain "pie." Thus, in the classic context, an infarction involving the right precentral motor area would produce a left hemiplegia, and if it involved the postcentral region, a left hemianesthesia would be added. In like fashion different areas of brain infarction would produce the other classic stroke syndromes described for each cerebral circulatory region. While we are still far from a complete understanding of the workings of the human brain, a more modern, dynamic, and holistic picture has evolved over the last three or four decades.

**The Neuron and Its Connections**

Basic to a holistic concept of the brain is an understanding of its smallest structural element, the neuron. The neuron consists of a cell body with a highly arborized dendritic tree and axon. Scattered over the dendritic tree and the cell body are a vast number of terminal buttons from the axons of other cells carrying information which may be either excitatory or inhibitory. The numbers of these inputs can range from an average of 10,000 for a single cerebral cortical cell to over 100,000 per cell in the cerebellum. Although the single neuron is only capable of choosing between firing or not firing, this "simple" decision can depend on the analysis of many thousands of inputs, complicated by internal feedback loops and highly complex intertwinings of incoming messages in an infinite variety of permutations and combinations. Thus, we begin to see that no single cell of the nervous system functions independently of a vast array of information, making this "simple" decision to fire highly sophisticated indeed. The largest amount of the central nervous system white matter is utilized not by direct pathways, as was previously thought, but by internuncial neurons participating in feedback and feed-forward types of communication, interrelating all of the cells in a highly integrated whole and uniting the two sides of the central nervous system at every level of the neuraxis.

With the human brain containing over one billion such cells, we can begin to appreciate the organizational substratum of human thought and behavior. The simplest of activities such as taking an apple from a bowl requires the participation of a near totality of the
central nervous system as well as the entire musculo-
skeletal system. The apple must be seen and observed. It
must be recognized and remembered and the desire
formulated. Movement of the eyes, including adapta-
tion to light and distance, must precede coordinated
movement of the head and neck followed by integrated
realignment of the center of gravity and the musculo-
skeletal system, allowing the hand to reach forward
and in a coordinated and smooth fashion to grasp the
apple with the appropriate strength. This relatively
simple activity requires the participation of both sides
of the nervous system and the integrated function of
both halves of the body. When damage occurs in any
portion of the brain, not only are those functions which
might be the primary concern of that region disturbed,
but the entire brain suffers from the loss of communica-
tion with the injured portion. The remaining normal
portions of the brain are deprived of input from the
damaged area, and they are also subject to abnormal
messages and misinformation generated as a result of a
lesion.

From this basic understanding of the neuron, it is
seen that there is no such thing as a simple stroke with
only hemiplegia. The victim of the stroke will have
significant difficulties with both sides of the body, and
these difficulties will extend in some degree to all
functions of the brain. Motor function will be impaired
on both sides. Balance and coordination will not be the
same. Sensory perception and spatial orientation will
be impaired with far-reaching and often disastrous
effects. Memory, cognition, and behavior will all be
altered, often presenting the most formidable chal-
enges to rehabilitation.

Physiological Basis for Rehabilitation Techniques

Two major principles underlie the modern concepts
of plasticity in the central nervous system, on which a
great number of rehabilitative techniques are based.
The first is the polysensory function of the neuron.1
We can no longer think in terms of the classic giant cell
of Betz with its purely motor function initiating volun-
tary motor action via a discrete pyramidal tract to the
anterior horn cell. We must now think in terms of a
polysensory neuron receiving inputs from the visual
system, the auditory system, the vestibular system,
etc. Thus, if cells are deprived in one category of
input, they are capable of some degree of compensa-
tion via other inputs. These polysensory neurons or
pools of neurons are also capable of memory storage
with the degree of complexity that allows for human
thought and learning.

The second basic principle arises from the hierarchi-
cal structure of the nervous system as it slowly evolved
upward, culminating in the human brain. We tend to
think of finely tuned motor skills and dexterity as the
cortical prerogative of the higher primates and man.
However, one has only to think of the sea gull swoop-
ing down to pluck a fish from the water to admire the
finesse which can be accomplished almost entirely by
the basal ganglia in birds. We know that if we remove
the cerebral cortex from one hemisphere in cats and
dogs, almost no motor impairment is detected, al-
though the animal has contralateral hemianopia. In
monkeys the cerebral cortex plays a much more impor-
tant role, and removal of the "precentral motor cor-
tex" or all of the cortex from one hemisphere will
produce a severe or total contralateral paralysis. After
a period of time, however, movement will begin to
return, and the monkey will regain significant function
in the lower extremities and some function of the upper
extremities.2,6 It has also been shown that each cere-
bral cortex provides a significant degree of ipsilateral
innervation and that the ipsilateral innervation is more
extensive in the lower extremities than in the upper.1,7

The ontogenetic development of the brain follows to
some extent the evolutionary development of the spe-
cies so that the phylogenetically older parts of the brain
are the first to mature with the newer cortical (neo)
system not fully matured until several years after birth.
It is these subcortical systems which provide the organ-
izational substrata for the vast multitude of reflex
activities that permit highly complex, bilaterally inte-
grated sensory and motor functions to take place with-
out impinging on cortical or conscious awareness. It is
through the use of these reflexes, both inhibitory and
facilitatory, that much useful function can be reac-
quired by the brain-damaged person and eventually
brought under the conscious control of the ipsilateral
and remaining contralateral portions of the brain.

Stroke Rehabilitation

Although there is a long-term downward trend in
stroke prevalence, cerebral vascular disease is still the
third most common cause of death in the United
States.8 Since intracerebral hemorrhage and major ce-
rebral emboli are associated with a higher mortality
rate than thrombotic stroke, the vast majority of pa-
ients seen in rehabilitation centers are those who have
suffered cerebral vascular thrombosis of arterioscle-
rotic origin or minor cerebral embolism.8,9

Spasticity

Treatment of spasticity is an overriding concern in
the treatment of the brain-damaged patient. Medica-
tions have proved to be useful adjuncts to physical
methods in treatment of spasticity. As with all condi-
tions, some patients will respond more readily to one
drug than another, and lack of significant improvement
with one does not prejudice the outcome that might be
achieved with a different medication. It must be em-
phasized that drug treatment alone is rarely, if ever,
sufficient and must always be combined with appro-
priate physical therapy, occupational therapy, and correct
rehabilitation nursing techniques, as well as selected
nerve block and surgical approaches.

Among the medications that we currently employ,
baclofen has proved helpful, starting with 10 mg orally
once a day and increasing slowly to a maximum of 20
mg three times a day. A certain degree of spasticity in
the lower extremity can be functionally useful, allow-
ing the hemiplegic patient to stand and walk without
the need for bracing at the knee. If the response to
antispastic medication is "too good," the patient may lose some functionally useful spasticity, and his overall level of achievement may be reduced rather than augmented.

Diazepam has been widely used to reduce spasticity and can be helpful in selected patients; however, potential disadvantages include a tendency to somnolence at higher doses and a propensity of this drug to increase the degree of depression that these patients frequently manifest. It can be most useful in those patients for whom spasticity is a particular problem at night and can be given for this purpose in a single evening dose. We have occasionally used dantrolene sodium for spasticity. In all instances the clinician should familiarize himself with the side effects and precautions of each agent.

Along with other neurological manifestations of reduced higher cortical control such as tremor and ataxia, spasticity is often aggravated by the patient's anxiety. In patients where this seems to be a factor, use of simple anti-anxiety medication can be most helpful.

Cognitive and Behavioral Changes

Neurological textbooks describe a large number of specific syndromes associated with lesions in precise areas of the brain purportedly causing limited cognitive dysfunction, such as the inability to recognize one's fingers and to do simple arithmetic (Gerstmann's syndrome), the inability to recognize faces (prosopagnosia) or to recognize streets or places, inability to read while maintaining other language (alexia), etc. These studies, for the most part, have been done by observations on patients with discrete tumors or small isolated infarctions as well as on patients undergoing neurosurgical procedures. While these syndromes have considerable theoretical and academic interest, their value in stroke rehabilitation is more restricted. Although the brain has been shown to have various localized areas subserving relatively specific functions, the high degree of integration and interdependence of all areas of the brain is such that any lesion, no matter how small, will manifest itself to a greater or lesser degree by creating a disturbance in the cognitive integrity of the whole.

The major function of the white matter is to insure transmission between neurons which provides the integration of functions of the various parts. Disturbance of this integrating ability causes the most profound disturbances in cognitive function by impairing perceptual awareness of the multiple sensory inputs as well as the integration of these inputs with appropriate motor responses. In the clinical setting of the typical stroke patient, we are dealing with an individual who often has diffuse cerebral vascular disease, perhaps previous episodes of stroke, and frequently other conditions contributing to impaired cerebral circulation, such as decreased cardiac output, hypercoagulability, and anemia. Therefore, from a practical standpoint we must consider that while one major area of infarction may have precipitated the hemiplegia which brought the patient to medical attention, there will often be areas of impaired function located diffusely throughout one or both hemispheres.

Studies of major asymmetrical functions of the two hemispheres reveal that the left hemisphere not only is predominant in localization of language functions, but also appears to be important for all types of mathematical and analytical thinking of the deductive type, while the right hemisphere is more involved with spatial orientation, body image, and inductive modes of reasoning. In approaching the rehabilitation of a stroke patient with a major lesion in one hemisphere, however, we must remember that normal thinking and carrying out of activities requires integrated function of both hemispheres, neither of which is really dominant over the other. For example, a professional writer who has sustained damage to the right hemisphere with "preserved" language function might still be able to communicate for routine daily activity and be able to write simple material, but his syntax will probably suffer and the ability to write creatively will be significantly impaired, as will other cognitive functioning.

Denial and Hemi-Inattention

Because of their inability to analyze and integrate incoming sensory matter due to the disruptive lesion of the brain and the internal production of abnormal signals, a high percentage of stroke patients have a form of denial of illness (anosognosia) and a lateralized denial of one-half of their own body and the environment on that side (hemi-inattention). It is important to realize that with this as with the other cognitive disturbances, the patient is unaware of the existence of these deficits and, therefore, will not complain of them. The examiner must elicit the information by direct questioning, testing, and observation. If the patient is able to communicate in the early post-stroke phase, he is quite likely to deny that he has any dysfunction. A patient with left hemiplegia, for example, might raise his right arm quite readily on request. When asked to raise his left arm, however, he may respond "I just did" or may raise his left arm by grasping it with the right hand and elevating it. When further questioned, he may report that it had moved perfectly well. Another patient, whom I recall, complained that a man in the next bed bothered her by keeping his hand on her breast, totally unaware that the hand she referred to was her own on the hemiplegic side. As the patient improves, this gross denial of illness usually recedes, but the hemi-inattention may persist.

These patients have considerable difficulty in spatial orientation. They are unable to localize stimuli, their own limbs, and objects in space. They may totally disregard stimuli coming from the involved side, even though they can hear, see, or feel those stimuli and are aware that they are occurring, occasionally localizing the stimulus and responding as though it were on the intact side. It is not uncommon to see a patient with hemiplegia wash, shave, comb, and dress only one side of the body, being totally unaware that he has neglected the other side, even though physically capable. Even after being presented with a mirror, the pa-
him with statements such as "Come on, John, you can do it if you only try harder."

The patient who misconstrues and poorly interprets sensory input and communications will also tend to explain these misinterpretations by unwarranted accusations against members of the family and the health professionals caring for him, leading to a type of paranoid behavior and hostility.

While some have considered the depressed attitude of the patient as a psychological response or grieving for their lost function, several significant differences between the depressed stroke patient and other forms of reactive depression make this explanation unlikely. The depressed stroke patient does not manifest the classic signs of insomnia and loss of appetite. They do not ordinarily respond to a psychotherapeutic approach, and standard antidepressant medications do not usually produce significant amelioration. In view of these inconsistencies with classic depressive neurosis and psychosis, we would suggest the term, organic pseudodepression, to characterize this condition.

Treatment and improvement of these patients can be achieved with the over-all rehabilitation team approach. Medications that we have found to be useful adjuncts are methylphenidate (Ritalin), 10 mg orally at 8 A.M. and 2 P.M., avoiding an evening dose which might disturb sleep, or dextroamphetamine, 2 to 5 mg orally at similar times or in a long-acting spansule form, 10 to 15 mg, once daily in the morning. We believe that these medications are helpful not only for their mood-elevating quality, but also for their ability to enhance the patient’s attention span and thereby perhaps improve interpretation of stimuli. These drugs are known to produce cortical excitation and in mini-
FIGURE 3.  Self portrait made by an artist who had sustained right hemisphere damage. Note inattention to detail on left side of drawing.

mally brain damaged children help to compensate in some measure for loss of cortical inhibitory function on lower centers.

Principles of Motor Rehabilitation

Damage to the cerebral cortex and integrative circuits typically produces a hemiplegia with spasticity such that the so-called "anti-gravity" muscles predominate over their antagonists. This predominance causes in the lower extremity an extension of the leg with external rotation as well as inversion and plantar flexion of the foot. There is also a tendency to traction or hiking of the pelvis and, in the upper extremity, a depression of the shoulder combined with internal rotation and flexion at the elbow and flexion of the wrist and fingers. This reflex spasticity is rapidly complicated by soft tissue contracture, tending to freeze the extremities in the abnormal posture. Much of the rehabilitation effort is directed toward correcting the postural deformation with techniques which encourage inhibitory reflexes in muscle groups that are contracted while stimulating facilitatory reflex contraction of the opposing muscles, along with various techniques to prevent or reduce the concomitant soft tissue contractures. It is important that the fight against the hemiplegic posture be carried out on a 24-hour basis, not only by the intermittent therapy session, but by correct posturing and positioning of the patient when in bed or sitting in a chair. The physician must insure that all health care personnel are aware of and practicing these techniques correctly, and the practitioner must educate the patient’s family to do likewise when treatment is rendered at home.

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