Neurotechnology for Brain Injury Fact Sheet

Clinical Applications and Resources

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Preface

This Factsheet, written by Jennifer French, Neurotech Network, in collaboration with Justin Stanley, BA, CBIS, Brain Injury Alliance of New Jersey, is offered as a resource. It is for informational purposes only. Further, it is not intended to cover all programs, treatments, or research in the field, nor is it an endorsement of any aspect of its content.

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WHAT TO EXPECT FROM THIS FACT SHEET?

You or someone you care about has sustained a brain injury. You have heard that there are many advances and interesting research occurring in the treatment and management of brain injuries. This Fact Sheet will help inform you about neurotechnology, a new field that offers technical devices and therapies for persons living with brain injury. This Fact Sheet is designed for informational purposes only. It will provide an overview of brain injuries and the various levels of injuries, common secondary conditions, as well as defining neuroplasticity and what that means to someone living with a brain injury. This fact sheet will also review some important aspects of neurotechnology, including the types of technologies and important issues to consider before pursuing the use of a device or therapy. One way in which this Fact Sheet might be useful is to serve as the basis for discussion with a trained medical professional who is familiar with your specific condition.

WHAT IS BRAIN INJURY?

Brain injury can be caused by any internal or external trauma to brain tissue that is not hereditary, present at birth, or degenerative. The causes of brain injury are broadly classified as either traumatic (injury caused by an external physical force, as in a car accident or sports concussion) or acquired (injury arising from internal causes, as in a blood clot or brain tumor).

The severity of brain injury can range from “mild”, i.e. a brief change in mental status or consciousness, to “severe”, i.e. an extended period of unconsciousness after the injury. Grading scales used to classify the severity of brain injury use several clinical criteria. One example of a scale is the Glasgow Coma Scale, which grades a person’s level of consciousness on a scale of 3—15 based on the level of verbal, motor, and eye-movement responsiveness to stimuli. Other criteria used to classify the severity of brain injury include the duration of post-traumatic amnesia and the duration of loss of consciousness.

The medical consequences of brain injury can extend beyond the initial complications caused by trauma to brain tissue and blood vessels. Additional complications can be caused by biochemical responses to trauma, post-traumatic swelling, and increased pressure within the skull. Surgeries to remove tumors, hematomas, or penetrating objects may result in further trauma to brain tissue and blood vessels. Medical complications can also arise as a result of trauma to parts of the brain involved in the regulation of breathing, swallowing, and movement; individuals with brain injury may require intubation and mechanical ventilation. When the symptoms persist, brain injury may then be considered a chronic medical condition—not a singular event, but the beginning of an ongoing process that impacts multiple organ systems and may cause or accelerate other diseases and disorders that can reduce life expectancy. A study conducted by Harvard and Columbia Universities discovered that caring for people who live with brain injuries will incur a lifetime cost of $600,000 to $5 million each, depending on the severity.

If you or a loved one has sustained a brain injury, you are no doubt familiar with the notion that brain injury has a chronic as well as an acute impact on physical, mental, and emotional health. You may have found yourself in the position of having to explain that brain injury is often an “invisible injury”, whose chronic effects extend well beyond the initial physical trauma addressed in the acute phases of care. The following section, which discusses common secondary conditions following brain injury, is meant to serve as a brief review. This review is provided here, so that it could serve as a reference in understanding the possible relevance of neurotechnology to these conditions.

- Respiratory Conditions. The brainstem, the base of the brain is involved in the automatic control of breathing. Damage to this area, or to parts of the brain which

regulate its activity, can result in complication to respiratory processes ranging from the need for respiratory therapy to the need for mechanical ventilation.

- Speech and Swallowing. The brainstem, and other parts of the brain involved in motor control of the lips, tongue and throat, can all be affected by brain injury. This can result in a number of issues, including the need to relearn chewing and swallowing during the acute rehabilitation process or lingering speech and communication deficits such as slurring of words. Injury to brain areas involved in the reception and expression of speech can compromise verbal and non-verbal communication.
- Seizures. Seizures are abnormal discharges of electrical activity in the brain that can interfere with normal brain electrical activity. Depending on what part of the brain is affected, a seizure can have varying effects. For example, seizures generated from the temporal lobes, a part of the brain involved in memory, emotion, and speech, can cause auditory-verbal hallucinations similar to those experienced in schizophrenia.
- Vision. Vision is our dominant sense and there are many parts of the brain involved in the reception and processing of visual input. Brain injury can affect parts of the nervous system involved in receiving visual input, like the optic nerves; or it can affect cortical processing areas. A number of different aspects of vision can be compromised by brain injury; for example, injury may cause blindness, the inability to see one half of the visual field, or the inability to recognize faces and other salient objects.
- Paresis and Paralysis. Paresis refers to weakness, and paralysis refers to complete inability to move the trunk or extremities. Either can be caused by brain injury, whether by direct injury to parts of the brain involved in motor control, or secondary factors such as weakness caused by muscular atrophy during extended loss of consciousness. One common weakness pattern after stroke is hemi-paresis, weakness of the side of the body that is opposite to the hemisphere affected by the brain injury.
- Pain and Spasticity. Pain and spasticity are common consequences of brain injury. The sense of pain is regulated by multiple systems in the brain and peripheral nervous system. Brain injury can result in increased sensitivity to pain, which may exacerbate existing tissue or nerve damage caused by the initial trauma. Spasticity, an abnormal increase in muscle tension, can result from injury to muscle reflex centers in the brain.
- Urinary Incontinence. Urinary incontinence after brain injury can be caused by injury to areas of the brain involved in the motor regulation, or sensory awareness, of urinary function. It can also be secondary to damage of peripheral nerves caused by trauma or downstream biochemical effects of brain injury.
- Sexual Dysfunction. There are multiple brain systems involved in sexual response and function, from reflex centers involved in arousal, to higher cortical centers involved in sensory and emotional aspects of sexual contact. Any of these systems can be compromised by brain injury, resulting in problems in sexual function ranging from physical issues, to disinhibition and dysregulation of sexual impulses.
- Pressure Sores and Wounds. Brain injury can interfere with the body's normal healing process, exacerbating pressure sores, that are secondary to long periods of immobility during loss of consciousness, or wounds caused during the initial trauma.
- Ambulation. Even in the absence of peripheral nerve or spinal cord injury, trauma to the brain can compromise motor coordination. Paresis and paralysis may result in gait abnormalities, loss of fine motor control, and the need for a wheelchair or other assistive devices. Injury to parts of the brain involved in maintaining a sense of one's body in space can result in neglect, in which a person is unaware of the side of their body contra-lateral to the site of injury, and may be incapable of moving that side. More severe forms of ambulatory disturbance after brain injury can result from damage to the brainstem and other areas involved in reflex control, such as "locked-in syndrome", where a person maintains conscious awareness, but is unable to achieve any form of movement beyond oculomotor control.

- Cognitive and Emotional Problems. Multiple systems of the brain are involved in the regulation of attention, alertness, and emotional responsivity. Any of these areas can be affected by brain injury, resulting in discrete deficits such as attention deficits, or global problems with cognitive and emotional control, like impulsivity and aggressiveness. Emotional problems can also be secondary to the actual injury, caused by difficulties in adjusting to the change in capacities and self-esteem resulting from brain injury.

WHAT IS NEUROTECHNOLOGY?

Neurotechnology is a broad term used to refer to medical electronics used to interact with the human nervous system. The field has made rapid advancements in recent history: components have shrunk, electronics improved, and we, as a society, have become more accepting of interacting with technology. For instance, think about how common a heart pacemaker is today compared to only two decades ago. Devices are available commercially for brain injury treatment in such areas as pain management, breathing assistance, rehabilitation techniques and diagnostic practices. There are also many new technologies being investigated in research centers. These devices cannot reverse the damage to the brain. They are tools that can be used, for instance, to combat secondary conditions, provide further independence or to aid in the rehabilitation process.

The basis of neurotechnology is the electrical signals the body uses to send messages. Electrical stimulation is the primary feature of this technology. Even though a muscle is paralyzed, it does not mean that the muscle cannot contract when it is stimulated. For those with mobility impairments that do not have peripheral nerve damage, electrical stimulation may be utilized; it is being demonstrated through exciting new technologies. The technologies are also being reviewed to excite neurons in the nervous system.

In the 1950's, the first attempt was made to apply electrical stimulation to the phrenic nerve to allow a person to breathe without a ventilator. This gradually developed into a field of science called FES (Functional Electrical Stimulation). FES encompasses a variety of therapeutic techniques and treatments used to activate muscles that may not be functioning properly due to injury, disease or a physical abnormality. Over the decades, this field of science that combines medicine, biomedical engineering and technology evolved into what is now called neurotechnology.

Areas of Neurotechnology

Neurotechnology can be divided into four areas: Neuromodulation, Neural Prostheses, Neural Rehabilitation, NeuroPharmaceutical, and NeuroSensing and Diagnostics. Each area has a distinct definition however some devices may be applicable to more than one area.

- *Neuromodulation* works by using electrical stimulation to improve control of an existing part of the nervous system. Some examples include the spinal cord stimulation systems used for chronic pain management that blocks pain signals to the brain and gastric stimulation systems, which are used to block the signals of hunger.
- *Neural Prostheses and Neural Rehabilitation* is used in conjunction of a planned training program to replace or improve function of an impaired nervous system. For instance, FES systems can restore some hand function for those with upper extremity impairments while drop foot stimulators can aid walking. Robotics may be used for repetitive therapy or suspension treadmill training systems can improve function of voluntary movement.
- *NeuroPharmaceutical* is an emerging field of therapy, applied through the use of devices combined with pharmaceuticals, particularly for cognition and emotional

treatments. Examples include pumps for baclofen to treat spasticity or morphine for chronic pain.

- *NeuroSensing and Diagnostics* are tools to improve monitoring of activity in the nervous system, brain state activity or improve diagnosis of a condition. A peripheral nerve sensing test system that detects sensory impairments due to carpal tunnel syndrome is an example of a neurosensing system in practice. Another example is EMG devices utilized to communicate with a computer system.

These four segments make up the innovative field of neurotechnology. This is an emerging field; it is essential that the consumer carefully consider each device, therapy or treatment protocol before choosing to participate.

Important Considerations of Use

Below are some important considerations to review prior to participating in a therapy, treatment or device use.

- It must be recognized that all neurotechnology programs may not be appropriate for all levels or people with brain injury. Researchers and clinicians currently working in this area understand the existing criteria and are developing new guidelines to determine for whom neurotechnology devices and therapies will be most beneficial and successful. Some levels of injury are more adaptable to some treatments than others.
- Systems are implanted, external or are a combination (hybrid) of both.
    - Implanted systems tend to be more "invasive" and therefore require a surgical or other procedure to install the system into the body of a potential user.
    - External systems are applied outside the body or on the surface of the skin.
    - Hybrid systems have components that are both implanted and external.
- The cost of the use of various systems is a very important consideration. In many cases, insurance does not reimburse for devices and therapies, especially if they are considered research or experimental. Review your insurance policy very carefully. **Do Not Agree** to participate in a protocol, therapy or research project until you have thoroughly explored the reimbursement options, out of pocket expenses and know the cost to you. You should be aware of your own health care policy coverage whether it is Medicare, Medicaid or a private insurance provider that may provide reimbursement.
- Be aware that such treatments, therapies or devices are potentially dangerous if not used correctly.
- Not all people with brain injury are appropriate for particular neurotechnologies. Your specific case should be reviewed by a medical professional prior to using any technology.
- Several neurotechnology devices and systems are still in a research phase and not available by prescription or purchase. Such devices might be available to participants in clinical trials. For more information about accessing clinical trials, as well as the risks involved, please visit www.clinicaltrials.gov.
- Listings of currently available devices and systems are maintained by the Neurotech Network (www.neurotechnetwork.org). As mentioned above, you should carefully review your insurance policy to establish whether these technologies are covered and what your out-of-pocket expenses might be. You should also discuss your interest in these devices with the treating doctors, including the neurologist, physiatrist, and other specialists.

Individuals interested in neurotechnology treatments, therapies or devices should consider the time commitment and financial requirements and be evaluated and supervised by a clinician specializing in brain injury.

WHAT IS NEUROPLASTICITY?

It was formerly an article of faith among scientists that damage to the brain was permanent, and neurons, once destroyed by trauma, could not regenerate. Decades of research into the brain have shown otherwise. There is a growing wave of scientific evidence for regenerative processes in the brain, and proof for the brain's innate plasticity—the natural capacity of the brain to “rewire” itself, to form new connections and re-model existing ones.

Cortical maps of the brain have shown the ability to modify bodily areas by sensory input and experience. Such studies about spatial navigation areas in the brains of taxi-drivers or areas corresponding to the motor maps of fingers in Braille readers demonstrate such capabilities of the brain. Axons, the projections that connect different cortical zones, continue to develop well into adulthood. Therapies guided by principles of neuroplasticity can encourage axonal re-growth, compensating for damaged neural tissue instead of re-growing it. There are neuronal assemblies, such as the hippocampus, which appear to possess limited regenerative properties, but research into this phenomenon is in its infancy. Nonetheless, as young as it is, the field of neuroplasticity is cause for cautious optimism among persons with brain injury and their families.

This research has obvious therapeutic implications for the treatment of brain injury. Doctors who specialize in the physical rehabilitation of patients with stroke have drawn on neuroplasticity research in devising therapies such as constraint-induced therapy, which forces use of the side of the body affected by stroke, by restricting use of the unaffected side. Forced to use the affected arm intensively and repetitively for weeks, stroke survivors will often see gains in their ability to use the impaired limb. Other more “low-tech” therapies drawing on the concept of neuroplasticity include compensatory therapies. The person with brain injury is trained to use a reminder system such as a notebook or calendar to compensate for memory or cognitive deficits. The continued use of such systems is hoped to encourage the growth of new habits, and, it is assumed, new axonal connections between regions of cortex spared by brain injury.

One of the most exciting realms of therapeutic technology, guided by the principles of research, is neurotechnology. This fact sheet outlines some of the current research areas in this field and offers practical guidelines for taking advantage of these advances. Families and persons with brain injury should be aware of these findings, and discuss them with their doctors. The inherent limitations in recovery caused by the loss of neural tissue can be balanced with the capacity for recovery offered by therapy and technology.

There are no “quick-fix-its” for brain injury just as there is no cure-all for any chronic health condition. We do not intend to offer false hope or make promises beyond what qualified medical professionals can make. Nonetheless, research into the regenerative properties of the brain can serve as a “silver lining” in the cloud of trauma and impairment caused by brain injury.

APPLICATIONS

Here is a brief introduction to advances that are currently available, as well as some resources that will help you stay updated on what is coming in the near future. This section describes the applications for some different areas related to brain injuries. ***Again, not all devices and therapies are appropriate for all injury levels. Consult a physician prior to any use.***

BREATHING ASSISTANCE AND DYSPHASIA

Some people with brain injury may expertience hypoventilation or difficulty breathing. Current neurotechnology alternatives to mechanical ventilation are hybrid systems that include either a phrenic nerve stimulator or diaphragmatic stimulator. Unlike ventilator systems that use mechanical pressure to force air into the lungs, the stimulation system pulls air into the lungs by stimulating the diaphragm muscle or the phrenic nerve. As the diaphragm contracts, the chest cavity expands and air is pulled into the lungs. As the diaphragm relaxes, the chest cavity naturally retracts and air pushes out of the lungs. The use of a breathing stimulation system is only possible if the diaphragm and lungs are intact and phrenic nerves are responsive to stimulation, thus allowing the system to work using these body parts.

Persons with brain injury can have paralysis of the muscles responsible for coughing. Cough assistance systems (CAS) are vital to reduce the frequent respiratory complications that can occur. CAS currently available use different pressures to clear the lungs through an external breathing mask attached to a separate control unit. It applies pressure to the airway and then rapidly changes the pressure to create a high outflow from the lungs.

Dysphasia, or difficulty swallowing, can also be an issue for those with brain injuries. The inability to properly swallow can inhibit basic eating and drinking functions or lead to much higher risk of pneumonia. Electrical stimulation systems can assist with this process. Using external stimulation, electrodes are placed in the throat area and stimulate the muscles involved in swallowing. This system provides a modality for exercising the same muscles and possibly improve swallow. More sophisticated neural prostheses to restore swallowing are currently under investigation.

COMMUNICATION DEVICES AND SPEECH THERAPY

Brain injury can result in a wide spectrum of communication impairments. Less severe, but no less disabling losses of communication ability can be caused by localized injury to cortical areas involved in speech production or comprehension, and by paralysis and hemiplegia that affects the mouth, tongue, lips and larynx. The most severe is total loss of the ability to speak in which an individual loses all or almost all-motor function, and hence loses capacity to speak. This is a condition called ‘locked-in syndrome’. It can result from injury to the brainstem.

Neurotechnology devices for communication impairments have few options for the most severe form of brain injury, caused by brainstem lesions or neurodegenerative conditions. In these conditions, there is almost total paralysis of the muscles involved in speech production, so the solution is to allow the person to communicate indirectly, through a computer interface. Since hands are also paralyzed by these conditions, the interface must be capable of hands-free operation.

If there is some muscle preservation around the eye or forehead area, communication may be possible using available electromyography (EMG) signals as an interface with a computer. Here the user is able to perform such tasks as writing email, surfing the internet and communicating via text-to-speech through the computer using the captured EMG signals. The latest research for severe forms of communication impairments are exploring the development

of brain-computer interfaces (BCI) that process signals generated by the brain using electroencephalographic signals (EEG), and translate these signals into words. The current generation of such BCIs translate EEG signals into letters, and so allow the person affected by brain injury to communicate one letter at a time. The downside of this approach is its slow processing rate, which prevents the individual from communicating in real time. Future BCIs are in development which would translate more specific signals for intentions, such as motor intentions read from the cerebral cortex, into words and phrases, allowing for a faster and more natural rate of communication.

Other forms of communication impairment can result in partial paralysis or weakness (plegia) to muscles of the mouth, tongue, lips and larynx. If the injury only affects peripheral nerves and muscles, there will be preserved capacity of the brain to comprehend and produce speech, but the end result will be slurred and slowed rate of speech. This condition is called dysarthria, and is also accompanied by dysphagia. For these conditions, the common form of intervention is electrical stimulation of the affected muscles, with electrodes being placed in the throat area. In fact, the speech therapist who oversees therapy for dysphagia will also be incorporating restoration of speech function as a goal of therapeutic exercises that accompany the use of electrical stimulation. For safety reasons, paralysis of facial muscles cannot be treated through electric stimulation, though advances in technology may expand the range of treatment options for this form of paralysis in the future.

Localized injury to cortical areas involved in speech comprehension and expression can also result in a myriad of communication impairments, ranging from difficulties in articulating, with relatively preserved verbal comprehension, to “fluent” aphasia in which speech is easy and fluent, but verbal production is compromised to the point of incomprehension (called ‘word salad’). Neurotechnological developments for treatment of aphasia are in their infancy, as the brain components involved in speech are broadly distributed and difficult to disentangle from other cognitive functions. There are clinical trials being undertaken to study the efficacy of targeted electrical stimulation of cortical areas involved in speech, typically through repetitive transcortical magnetic stimulation (rTMS) provided as an adjunct to traditional speech therapy.

Augmented and alternative communication (AAC) devices are a time-tested form of intervention for the aphasic disorders, allowing a person to communicate using a specialized touch screen device or another variety of personal computer like an iPad or iPhone equipped with specialized applications. Use of these devices coupled with speech therapy is routine in cognitive rehabilitation for speech impairments; in the future, electrical stimulation of cortical areas involved in speech may also accompany use of AAC devices in the hopes of stimulating functional gains deriving from rehabilitation therapies.

SEIZURE MANAGEMENT

Posttraumatic Epilepsy (PTE) is defined as two or more unprovoked seizures after a severe brain injury. Those occurring within a week of a brain injury are considered provoked seizures. In a population-based study, the incidence of PTE correlatively increases with the severity of the brain injury. Approximately two-thirds of people with a severe traumatic brain injury experience at least one seizure within a year and approximately 80% within two years of the injury. There are various means of managing the occurrence of seizures. This section will address only the neurotechnology options.

Approved by the FDA in 1997, vagus nerve stimulation (VNS) therapy became available to reduce the frequency of seizures in adults and adolescents with partial onset seizures. The device is targeted toward those with refractory epilepsy. A study published in 2008, studied the effects of VNS on people with PTE due to brain injury. The study evaluated 11 participants

before and after implantation of VNS. After 6 months, all participants showed an average seizure reduction of 74%. After 24 months, six participants were seizure-free. Although not specifically FDA approved for PTE, there are studies supporting the use of VNS for PTE.

VNS therapy is a fully implanted device consisting of a neurostimulator about the size of a pocket watch, lead wires and electrodes. No component protrudes from the skin. The stimulator is implanted in the upper left chest. Lead wires are tunneled under the skin up the neck where a bipolar lead is wrapped around the left vagus nerve. The device operates by providing intermittently pulsed electrical signals to the vagus nerve which in turn activates various areas of the brain. The surgery typically takes 45 minutes to 1 hour. The device is then programmed externally to adjust the system to the individual needs of the user. Along with the implanted system, an external special magnet is provided to allow the user control over the system. It is used to permit extra stimulation to potentially stop or shorten a seizure and by permitting an interruption of stimulation to manage side effects. The most commonly reported side effects from stimulation include but not limited to hoarseness (voice alteration), paresthesia (prickling feeling in the skin), dyspnea (shortness of breath), sore throat and increased coughing. Since 1999, CMS (Medicare/Medicaid) has a full coverage policy for VNS for refractory epilepsy and several private insurance companies have followed this lead.

Additional experimental treatments are being investigated for seizure management. These include RNS (Responsive NeuroStimulator) ® therapy as well as deep brain stimulation therapy. Both therapies are actively being studied in human clinical trials however neither is FDA approved for the treatment of refractory epilepsy.

Imaging and diagnostics are the other neurotechnology advancement for seizure management. Resection surgery is a consideration common among specialists to remove the seizure focus. Resection surgery involves the removal of the epileptic focus (seizure-causing) neural tissue in the brain. The difficulty for PTE is for those who have multiple epileptic foci, no identifiable epileptic focus or an epileptic focus that is not amenable to surgical resection. Advancements in diagnostic technology can with imaging of these distinct areas of the brain. Technology such as EEG and MEG can help medical professionals to gain a more detailed view of the activity of the brain. A particularly helpful advancement has not only been the amount of channels for neurosensing, but also the increasing acuity of the imaging to better guide the area of the human brain. This not only aids in diagnostics of PTE but also pre-surgical guidance in the “eloquent” areas of the human brain.

VISION AND CORTICAL BLINDNESS

Visual training, used by athletes in sports such as hockey, football and tennis, may now be used to assist with the rehabilitation of vision deficits due to brain injury or stroke. In the case of brain injury, vision deficits can be wide-ranging such as loss of peripheral vision, difficulty with visuomotor skills, or even slowed processing of visual information.

The ability to partially repair or regain a degree of visual function may not fully restore vision but may provide significant enhancements in quality of life. Visual rehabilitation approaches cluster around technologies such as prism adaptation glasses, computer programs that challenge visuomotor skills, and other optometric tools. Although more research needs to be completed in the clinical setting, vision rehabilitation tools, such as virtual reality system, using repetitive motion and processing are shown to improve hand-eye coordination and reaction times, to increase the speed, accuracy and efficiency of processing visual information, and to improve visuomotor compensation in both static and dynamic environments.

UPPER EXTREMITY PARALYSIS OR HEMIPARESIS

The loss of hand, arm, and shoulder function due to a brain injury can severely restrict an individual's ability to independently perform activities such as eating and personal hygiene. Regaining hand function is a high priority for persons with brain injuries. Although neurotechnology devices cannot restore the damaged neurons, they may help the brain generate new neural pathways or reallocate existing neural pathways to restore function. Neuromuscular electrical stimulation (NMES) devices can produce arm elevation and elbow extension for reaching and hand opening and closing for grasping objects. These devices can be used to enhance rehabilitation and improve recovery or to assist one with daily activities. NMES makes paralyzed or weak muscles move by activating motor neurons in the nerves that go to the muscles. Therefore, the peripheral nerves must not be damaged for the electrical stimulation device to work. Some NMES devices can be set to automatically turn on and stimulate muscles for several seconds and then turn off for several seconds and repeat this cycle to exercise the muscles. NMES devices typically give users control of the stimulation so that they can select desired movements using stimulation to their arm and hand.

Commercially available NMES devices generally are external systems that use electrodes that stick to the skin over the muscles to be stimulated (surface stimulation). These devices are used for exercise, muscle conditioning, and limited functional use. For instance, some external systems use repetitive motion therapy or combine external electrodes and EMG signals to enhance the rehabilitation process. Robotic systems may also be used to help individuals practice repetitive motions in order to assist in the neural rehabilitation process.

Shoulder subluxation or "drop shoulder" can also occur among people living with brain injury. As a result of muscle weakness or paralysis, the shoulder is dislocated from the proper position. This can cause dysfunction and also pain in the shoulder area. Shoulder slings are the most common treatment; however, neurotechnology may provide additional treatment and rehabilitation options. Electrical stimulation of shoulder muscles may help reduce or prevent pain, realign muscles, increase strength or encourage voluntary movement within the shoulder area.

PAIN AND SPASTICITY MANAGEMENT

Neuropathic pain (resulting from damage to nerves) is a significant problem in some people. Discussion with your physician can help you better understand where the pain is coming from and with that understanding, what can be done about it. Pain from brain injury can come from a variety of areas; it may be migraine pain or peripheral nerve pain. Additionally, pain can be related to the disability of paralysis; it includes over-use of joints or body parts, muscle spasm pain, or instability of the spine or other body organs. Even after mild brain injury, various forms of long-lasting cervical pain, and pain of the muscles of the neck and scalp, may be experienced as a result of mechanically induced trauma. Conservative medical management (CMM) for people with brain injuries should not only include therapies directed toward relief of pain such as taking of pain medicines or interventions such as needle injections of medications, but also include conventional physical therapies and rehabilitation, psychological and behavioral interventions. Your neurologist or physiatrist can provide a referral to a medical specialist trained in the field of interventional pain medicine.

We will discuss three areas of treatment that are currently available; transcutaneous electrical nerve stimulation (TENS), implanted drug delivery systems (IDDS) and spinal cord stimulators (SCS). There are other new areas of neurotechnology for the treatment of pain, such as deep brain stimulation and transcranial magnetic stimulation; which are not currently clinically available.

- ***TENS units (transcutaneous electrical nerve stimulation)*** work by delivering low-level electrical stimulation through electrodes placed directly on the skin of the affected area. The contraction of muscles through electrical stimulation may help alleviate pain by blocking pain messages being sent to the brain. The use of TENS or NMES (neuromuscular electrical stimulation, see Exercise and Rehabilitation section) to the spastic muscle or nerve supply to the spastic muscle may reduce spasticity and improve function. However, to use this method to control spasticity, a home program must be designed and monitored by a trained therapist. Typically, results will not be realized until the treatment has been administered for 1-2 hours per day for 1-3 months. TENS requires a physician prescription but this therapy can provide a convenient means of treating some forms of pain. TENS can be a non-invasive and economical solution.
- ***Implanted Drug Delivery Systems (IDDS),*** **also known as** ***Intrathecal Analgesia Therapy***, refers to the administration of medicine, either pain-relieving or spasticity-relieving, such as baclofen, by a medication delivery pump directly to the spinal canal. The IDDS include a chamber or reservoir for the drug that delivers the medication through a catheter directly into the spinal canal (intrathecal). The pump needs to be refilled, usually once every month or few months, by placing a needle through the skin. This procedure is typically performed on an outpatient basis or during a regular doctor's visit. Generally, a person first undergoes a trial of the medication by an intrathecal injection or continuous infusion of the medication through an implanted catheter. If successful, a pump system can be implanted permanently through a surgical procedure. IDDS reduces the need for oral medications, can be more effective and is now a mainstay of therapy for intractable pain including neuropathic pain and spasticity as a result of brain injury.
- ***Spinal Cord Stimulation (SCS)*** **system** is a hybrid system comprised of implanted electrodes in the spine, under the skin, or both and an external control unit. It uses electrical stimulation to block the pain pathways to the brain that travel through the spinal cord. The abnormal sensations experienced by people with brain injury are particularly suitable to spinal cord stimulation. SCS has also been known to decrease spasticity. An initial trial is needed to see if effective results can be achieved. If the trial is successful, a permanent system may be implanted. The user has the ability to keep the system on permanently or as needed.

These options should be discussed with a medical professional trained in interventional pain medicine.

URINARY FUNCTION AND BLADDER MANAGEMENT

A consequence of living with a brain injury may be reduced bladder control requiring the use of either an external or internal catheter. Neurotechnology devices offer an alternative method of bladder management that uses electrical stimulation to control urination or "voiding". Several different approaches have been developed to treat the hyper-reflexive or flaccid bladder. Hybrid devices may stimulate the sacral, tibial, or pudendal nerves or the bladder muscle itself in order to provide bladder function. The external pelvic stimulator uses electrical stimulation delivered by a vaginal or anal probe. The appropriateness of each specific device or treatment depends on the incontinence severity and bladder condition. There are five basic types of devices using electrical stimulation in different ways. These include:

- The **sacral nerve stimulator** is an implanted device that manages the bladder by sending electrical impulses to the nerve that controls the bladder, its sphincter, the muscles around it, and the sacral nerve roots,
- The **tibial nerve stimulator** controls the bladder through percutaneous stimulation (an electrode inserted through the skin) of the tibial nerve in the lower leg.
- The **pelvic stimulator** is completely external and uses electrical stimulation applied to the pelvic floor muscle. Generally delivered by a vaginal or anal probe connected to an external pulse generator, stimulation of the pelvic muscles may improve the opening and closing of the urethra.
- The **bladder muscle stimulator** is a device that directly stimulates the bladder muscle with an implanted electrode.

- An implanted device, soon to be in clinical trials, uses an electrode to stimulate the pudendal nerve to provide bladder function.

Each of these therapies can help improve control of the bladder, provide peace of mind and offer more independence. These are options aside from widely available pharmaceutical options. However, these approaches should be discussed with your urologist and evaluated for your individual situation to determine which may or may not be appropriate for you. Please note that in some instances, bowel function may coincidently exhibit benefits from the use of stimulators for urinary function.

PRESSURE SORE PREVENTION AND WOUND THERAPY

People living with brain injury who are sedentary and who have absent or reduced sensation are at high risk of developing pressure ulcers due to muscle atrophy, decreased mobility and altered sensation. The prevention of pressure ulcers is a lifetime health issue. Daily use of electrical stimulation can help maintain the bulk or mass of paralyzed muscles. Results may not be realized until the stimulation has been applied for 1-2 hours per day for several months. External electrical stimulation has some practical problems because electrode placement over the nerve that stimulates the buttock region can be difficult for users to achieve and it may not be possible to achieve a strong muscle response. However, external electrical stimulation also offers an economic approach for a home-based therapy.

The use of electrical stimulation for the treatment of wounds has long been used in clinical practice. Electrical stimulation (ES) for pressure ulcer treatment is one of only two therapeutic options recommended by the Agency for Health Care Policy and Research for severe chronic wounds. A wide variety of external stimulation devices, approved by the Food and Drug Administration (FDA) for other purposes, may be adapted for use in wound therapy. Currently approved clinical use is limited to application of electrotherapy only after there are no measurable signs of healing for at least 30 days of treatment using conventional wound treatments. Devices targeted for wound therapy are currently available and new devices are being developed.

Implanted stimulation systems for long-term therapeutic use have dual advantages; 1) the electrode can be located very close to the targeted nerve for muscle contraction and 2) repetitive placement is no longer an issue. Two research teams are investigating implanted stimulation systems. Dr. Kath Bogie's team at the Louis Stokes Cleveland Department of Veterans Affairs Medical Center is investigating the use of a gluteal electrical stimulation system (GSTIM) specifically to decrease risk factors associated with pressure ulcer development for individuals susceptible to pressure sores. Studies such as this have focused on the spinal cord injury population but may have future applications to those living with brain injury and immobility.

AMBULATION SYSTEMS

There are a number of neurotechnology systems available to assist with walking. Many of the systems available today were developed specifically for survivors of stroke. As the neurological deficits associated with stroke and brain injury may be similar, some of these neurotechnology devices have been proven to be beneficial for persons with a brain injury. Brain injury is complex in that there are a variety of different symptoms which can contribute to ambulation issues. Such symptoms can range from sensory or proprioceptive feedback to visual perception or from auditory reception to extreme spasticity. It is important to properly identify the inhibiting symptoms prior to introducing a technology for assistance.

There are two basic types of ambulation systems, those which are used to target recovery (therapeutic) and those which are used to take over for a lost ability to move (compensatory). In some cases, the systems can provide both a compensatory and therapeutic benefit. Ambulation systems that target recovery are used in the rehabilitation process often in conjunction with physical therapy to augment the recovery of walking. Ambulation systems that compensate for the individuals loss of movement often work on the affected limb during a functional activity to assist with movement that was lost due to the injury. It is important to recognize that many of these systems are currently not considered standard care and therefore may not be covered under health insurance.

Therapeutic Systems in Rehabilitation

There are several body weight support and robotic systems that have been developed to assist with the recovery of walking. A body weight support system may be utilized to support a survivor's body weight while they practice walking over a treadmill or over ground with or without the assistance of a therapist. The robotic systems can also record and react to the user's movements automatically leading to improvements in walking. The use of these walking systems allow for repetitive practice of walking in a controlled and safe environment. This has been proven to benefit walking recovery. There are additional technologies being developed that can interact with the body's own sensing receptors, such as vision, to improve balance and walking.

Assistive Devices in Neural Prosthesis

Neural prosthesis systems provide basic standing and stepping; these provide additional assistance for those with loss of voluntary movement. Robotic exoskeletons are an example of assistive ambulation systems that are currently under investigation. These are electronic suits worn with a power supply. The use of these devices provides ambulation in the absence of voluntary movement. The exoskeleton provides the movement while the user provides the balance with crutches. Functional electrical stimulation (FES) systems which use electrodes temporarily placed on the skin surface are commercially available and others are under investigation.

Foot drop is one of the most common walking problems caused by brain injury. Persons with foot drop are unable to raise the front part of their foot because of weakness or paralysis of the muscle(s) that normally lift the foot. A person with foot drop has difficulty "clearing" their foot while walking which results in dragging or scuffing of the foot/toes along the ground when they are moving the leg forward. As a result, the person with foot drop will compensate by adjusting the way they walk. Foot drop is traditionally treated with an ankle foot orthosis (AFO), a compensatory treatment strategy. An alternative to an AFO is the use of functional electrical stimulation (FES), both a compensatory and therapeutic treatment strategy. FES sends small pulses of electrical stimulation to the nerve that controls the muscles that lift the foot. The stimulation is given in a specific sequence to help with functional movement of the foot during walking. The benefits of FES for the treatment of foot drop include an improvement in walking speed, distance walked, participation in social activities, and a decrease in reported falls. There is evolving evidence that over time, walking speed without the FES system improves. However, that improvement remains less than that seen with the device still on.

It is important to note that not all people living with brain injury will have the reflex or muscle contraction to achieve independent walking. However, the evolution and development of walking systems will continue to improve the potential for recovery of walking with or without ambulatory aids, such as walkers and cane, after a brain injury.

EXERCISE SYSTEMS

Exercise is an important part of a healthy lifestyle. Exercise can assist in the rehabilitation process after a significant injury and prevent injuries. For people with a brain injury, exercise is important during the initial stages of recovery to help individuals regain the ability to perform everyday activities and mobility as well as when active rehabilitation is over as part of a wellness and prevention program. Specific exercises can promote positive changes in the brain and help people re-learn mobility tasks such as walking. Exercise improves cardiovascular and pulmonary function and reduces the chance of developing potentially disabling secondary effects of brain injury such as contractures and fatigue. After rehabilitation, just as with people without a brain injury exercise has many beneficial health effects. Exercise can reduce the risk of heart disease, cancer, obesity, and other disabling health conditions.

Advances in neurotechnologies can be used to help people with a brain injury exercise even if they have limited ability to move themselves. Initially after a brain injury muscles may be weak or paralyzed and individuals may have abnormal movement patterns. Neuromuscular electrical stimulation (NMES) utilizes electrical activity to cause weak or paralyzed muscles to contract. NMES can be used to help strengthen weakened muscles or move limbs and joints in a functional way. This is called functional electrical stimulation (FES). FES can be used on lower leg muscles while walking to prevent foot drop or to move the wrist and fingers to grasp and release objects. There are certain precautions that should be observed when using NMES. You should consult your rehabilitation professional to make sure it is safe for you to use these devices when exercising.

Multiple repetitions during exercise are necessary to promote the positive effects of exercise. NMES and other neurotechnologies such as robotic devices can help people with brain injury complete the necessary repetitions to gain the benefits of exercise and rehabilitation. For example, gait training using body weight support systems and a treadmill with or without FES and robotic devices to assist with moving the legs is an effective way to improve a person's ability to walk. It may also have other beneficial effects such as improving cardiovascular health and balance.

Virtual reality is another technology that can facilitate exercise. Virtual reality and gaming can be incorporated into an exercise program to make it more exciting, challenging, and motivate people with brain injury to exercise.

COGNITIVE AND EMOTIONAL MANAGEMENT

A brain injury of any severity can lead to cognitive and emotional problems. Cognitive difficulties may have a wide range of implications such as slowed rate of processing, loss of attention control, and memory impairments. This also includes devastating diminishments in arousal and awareness that characterize disorders of consciousness such as minimally conscious and persistent vegetative states. Emotional difficulties can be primary or secondary caused by injury to areas of the brain involved with the recognition, display, or inhibition of emotions; or by an individual’s reaction to the personal losses that are the inevitable products of a brain injury. Brain injury may lead to psychiatric symptoms including depression, anxiety, and emotional lability.

Therapeutic interventions for cognitive impairments may include cognitive rehabilitation in group or individual settings; certain classes of medication including stimulants may be used to increase cognitive function. Researchers have conducted studies of electrical stimulation to the brain, through transcranial magnetic stimulation (TMS) and electrodes implanted in subcortical sites, known as deep brain stimulation (DBS).

TMS is a non-invasive procedure that involves use of an electromagnetic stimulation device positioned precisely over the scalp to transmit repetitive magnetic pulses to the brain's surface. Several studies have explored the use of TMS to ameliorate cognitive difficulties arising from altered brain function after localized lesions, such as those in the prefrontal cortex. Given the distributed nature of brain function it is difficult to precisely target TMS interventions, but there are few, if any, side effects to the use of TMS. This technology is currently being used in the clinical setting for brain injury and is FDA cleared for the treatment of major depressive disorders. Alternatively, the pace of research is continuing briskly for a broader range of treatment conditions with many clinical trials becoming available at universities and hospitals.

DBS involves implanting an electrical neurostimulation device under the cortical surface, typically in the thalamus, a subcortical site which is a "relay station" routing sensory and motor signals to distributed networks in other areas of the brain. .Preliminary results show that DBS can boost arousal in patients with disorders of consciousness, and the future direction of DBS research is likely to investigate its efficacy for moderate cognitive impairment as well. Intelect Medical has taken the lead in the research and development of DBS neurotechnologies, drawing on the important clinical discoveries of Drs. Nicholas Schiff and Ali Reza.

These neurostimulatory technologies may be efficacious in treating psychiatric conditions secondary to brain injury, like anxiety, depression or aggression, if they have proven refractory to conventional therapies or medication. Clinical studies are being conducted on the use of TMS to localized cortical areas. In more severe cases, studies are being conducted which implant DBS electrodes in limbic and thalamic regions, to correct the imbalance of hemispheric regulation which results in emotion regulation difficulties. Another technology feasible for treating psychiatric conditions is vagus nerve stimulation (VNS), typically used for intractable epilepsy; VNS has also shown promise in treating depression. These studies face the same problem as the use of neurotechnology for cognitive problems—the distributed nature of neural function—but research is moving swiftly, encouraged by findings from the use of these technologies in other conditions.

RESEARCH APPLICATIONS AND FUTURE DEVELOPMENT

This section highlights some of the most recent technology development and advances in research being studied in the form of clinical trials. These technologies are most current as of the writing of this Fact Sheet. Research developments change frequently. Please visit www.clinicaltrials.gov to learn more about the risks and aspects associated with clinical trials.

Motor Relearning

Advances in rehabilitation therapy are currently being explored in the area of motor relearning. For stroke survivors and others who have a brain deficit, coordinating what they see with body movement is very difficult. Visual impairments such as loss of peripheral vision or visual field cuts act synergistically with motor impairments to restrict an individual's range of vision and abilities to navigate activities of daily living. Technology in the form of a Cyberglove is being studied to assist people remap or relearn the visual inputs associated with the sensory inputs to the brain. The goal is to eventually create individualized physical therapy approaches to fit the specific needs of each person.

Electrode development

A key component of neurotechnology systems using electrical stimulation or sensing is the electrode. The stretchable microelectrode array may be a powerful new tool in traumatic brain injury research. Flexible arrays will allow researchers at Columbia University and Princeton University to replicate injuries in the lab without destroying the electrodes that monitor how brain cells respond to physical trauma. The devices feature microelectrodes that are able to withstand the sudden stretching that is used to simulate severe head trauma. The systems could allow for a better understanding of brain injury and may lead to better treatments in the minutes and hours immediately following the injury. The work also has implications for other areas of medicine, including next-generation prosthetics.

Laser Therapy

Studies undertaken by PhotoThera are investigating the effects of transcranial laser irruption following traumatic brain injury, effects of transcranial therapy applied after induced stroke, and neurological effects of laser irradiation on intact brains using various power densities and number of sessions. Looking to the future, PhotoThera plans to use its NeuroThera technology to treat a broad range of diseases and health conditions. Future clinical applications include brain injury, global cerebral ischemia, Alzheimer's disease, Parkinson's disease, spinal cord injury, and sepsis.

Transcranial Light Therapy

Similar to Laser Therapy, transcranial infrared light therapy is being investigated to improve cognitive function in persons living with traumatic brain injuries. The therapy being studied is a non-invasive treatment, suitable for home treatments; which include light-emitting diodes (LEDS) placed on the forehead and scalp. In preliminary early stage studies, participants show regress of improvements within one to two weeks of stopping the therapy. Although the initial results are promising, further studies are needed.

Deep Brain Stimulation

Deep Brain Stimulation (DBS) has been used for the treatment of tremors associated with Parkinson's disease. Most recently, research studies have been conducted to use this intervention in people living with a post-traumatic minimally conscious state. Under the current standard of care, most people living in MCS do not receive active rehabilitation. This applied neurotechnology is being used to stimulate arousal as well as higher levels of functioning such

as speech and movement. Early stage research is currently underway in an FDA approved pilot study.

Transcranial Magnetic Stimulation

Transcranial Magnetic Stimulation (TMS) has been used for the diagnosis of muscle, and other motor system weakness, in neurological conditions, and experimentally as a treatment for medication-resistant depression. TMS is non-invasive, using an electromagnetic field generator to apply carefully targeted currents to specific areas of the cortical surface. TMS has been FDA approved for the treatment of depression and is being studied as an adjunct to rehabilitative therapies following brain injury.

Summary and Disclaimer

This Fact Sheet is an overview and explanation of the applications of neurotechnology for several different conditions related to brain injury. Devices are commercially available that are used for pain management, spasticity control, breathing assistance, exercise, ambulation and bladder function. There are also many new technologies being investigated in research centers. These are tools that can be used to combat secondary conditions, foster or encourage further independence and/or potentially improve quality of life. These technologies are not a one-size-fits-all and not everyone is appropriate for a particular technology.

Prior to considering any new therapy, treatment or device, a proper evaluation must be conducted with a knowledgeable medical professional. There are health, medical and financial risks. Out of pocket costs and available insurance coverage for any treatment must be considered prior to starting a protocol. A medical professional familiar with your particular condition should be consulted. Finally, this is an evolving field of science and technology development. The frequent changes are occurring in this new field of technology.

Neurotech Network, The Brain Injury Alliance of New Jersey and its representatives do not rate, endorse, recommend, sell, distribute or prescribe any products, procedures or services. This fact sheet is for informational purposes only.

Suggested Reading

- Neurotech Network, an educational website with a database of devices. http://www.neurotechnetwork.org/
- Clinical trials.gov, search terms with brain injury, brain trauma, stroke, and any of the following: electrical stimulation, neuromuscular stimulation, spinal cord stimulation, exercise, urinary, sexual function, walking, hand function, cough, respiratory.
- IFESS Consumer Information: http://www.ifess.org/Services/ConsumerEd.htm
- National Institutes of Health, National Institute of Neurological Disorders and Stroke – Neural Interfaces Program: http://www.ninds.nih.gov/funding/research/npp/index.htm
- International Neuromodulation Society - http://www.neuromodulation.com/about-neuromodulation.htm

Glossary of Terms

Biomedical engineering. The application of engineering principles to biology and medicine.

Contraction. The shortening of muscle fibers due to activation of a muscle by voluntary or external means.

Diaphragm. A dome-shaped muscle that separates the chest and abdominal cavities. It aids breathing by its upward and downward movements.

Electrotherapy. The clinical practice of applying electricity to the body to achieve a therapeutic result. This would include FES applications such as muscle strengthening; wound healing, contracture prevention and improving circulation.

Exoskeleton suits. A garment-type device used as an external supportive-covering over the body.

Extension. A movement that increases the angle between two adjoining bones of the skeletal system.

External system. A medical device system that is applied to the outside of the body such as the surface of the skin.

Hybrid system. A system that has both implanted and external components. See also, External system and Implanted system.

Implanted system. A medical device system which is surgically placed in the body.

Intrathecal. An injection into the spinal canal (intrathecal space surrounding the spinal cord) of a drug or other therapy, such applications include anesthesia, chemotherapy and pain management.

Movement enhancement devices. Devices used to aid in the reconditioning of weak muscles with applied movements.

Neuromodulation. A technology that acts directly upon nerves to alter or modulate nerve activity by delivering electrical or drug related agents to a targeted area of the body.

Neural Prosthesis. A device which acts to replace or improve function of a missing or impaired part of the body.

NeuroRehabilitation. The use of a nerve-related system applied to the body to provide healing or natural restoration of a missing or impaired body function.

NeuroSensing and Diagnostics. The use of a neural system to monitor or view the activity in the nervous system.

Neurotechnology. The application of medical electronics and engineering to the human nervous system.

Orthotic. A device used to support or brace a weak or disabled joint or muscle.

Oscillating. To move or travel back and forth between two points.

Protocol. A detailed plan of a scientific or medical experiment, treatment, or procedure.

Repetitive Motion Therapy. Treatment that includes assisted and voluntary motion of a limb

Robotics. Devices that automatically perform repetitive tasks used in neurorehabilitation.

Stimulation. A physical application that arouses or activates the function of sensory and/or motor nerves.

Transcutaneous stimulation. Stimulation to the skin surface over a muscle, peripheral nerve or skin nerve senses achieved by use of electrodes held to the skin by adhesive, tape, bandaging or tight-fitting garments.

Ventilator. A device for maintaining artificial respiration.

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