Nerve Injury, Nerve Reconstruction, and Recovery of Nerve Function

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The Problem

If you are reading this brochure, then most likely you have a problem related to a peripheral nerve. A "peripheral nerve" is a nerve that is outside the brain and outside the spinal cord, which are called the "central nervous system." Your problem may involve pain or loss of touch perception due to injury to a sensory nerve. Your problem may involve muscle weakness or paralysis due to injury to a motor nerve. Your problem may involve a combination of both sensory and motor nerves.

With an injury to a peripheral nerve, there is a good chance that your problem can be helped. This is because the cells that surround the peripheral nerve have the ability to make a nerve growth factor that permits these nerves to grow and restore function. The ability of the nerve injury to be corrected and for function to be restored is related to your age, the length of time since you were injured, the location of the nerve injury and the ability of the muscle to regain function.

Restoration of normal function and complete relief of pain are not always possible, but they are the goal. Often, a trade must be made to relieve pain. That trade will involve the loss of the injured nerve's sensory function in order to stop the pain signal from that injured nerve. Often, when an injured nerve is reconstructed, there is pain associated with the regrowth or regeneration of that nerve. Understanding why pain is associated with recovery of function will help you deal with this phase of your nerve reconstruction process.

It is the purpose of this pamphlet to give you the information necessary to appreciate the risks and potential benefits of the treatment of your nerve injury.

Anatomy

The skin is an interface between you and your environment. Just as your eyes and ears bring specific sensory information, sight and sound, into your body, the skin permits information about temperature, pressure and movement to be brought into your body. To do this, a network of nerve fibers connects the skin to the central nervous system (Figure I.) The information that comes through the skin travels in certain electrical messages to the spinal cord. There the messages are linked to filters in the brain stem that permit the electrical signals to be interpreted by the brain's cortex and appreciated by you as sensations of pain, temperature, and touch.

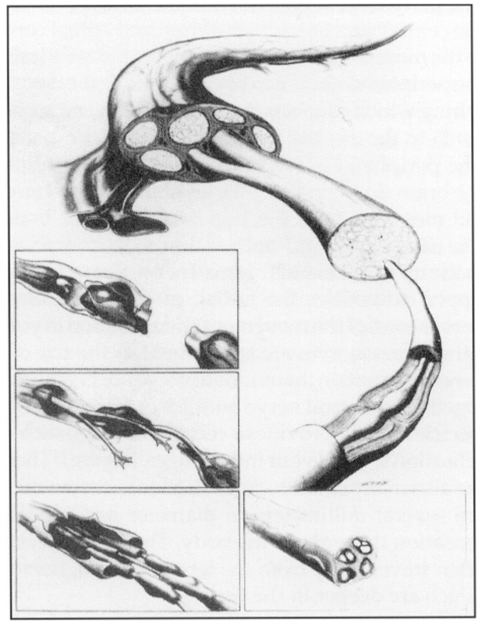

Figure 1. The nerve is made up of bundles or fascicles which in turn contain many nerve fibers. The inset boxes show the regeneration that occurs after a nerve is divided. Each single nerve fiber sprouts into a regenerating unit.

The small nerve fibers from the skin network form together into bigger nerves that are given names, such as the median nerve. The median nerve is the size of a pen or pencil in thickness and goes through the carpal tunnel at the wrist. Pressure upon this nerve causes the symptoms related to carpal tunnel syndrome, such as numbness and tingling in the fingers that contribute nerve fibers to this big nerve.

The small nerve fibers that are related to muscles join together with fibers from other muscles, and join together with fibers from sensory nerves to the skin that is usually in the same area of the body as these muscles. Usually, all large nerves, like the median nerve, contain both sensory and motor fibers. The median nerve, in addition to containing the sensory fibers from the thumb, index, and middle fingers, contains some of the motor fibers that help lift the thumb out of the palm.

Within the larger nerve, small groups of nerve fibers, that usually do the same thing, like provide sensibility to the index finger, travel together in a bundle or "fascicle".

Nerve Injury

Nerves are usually injured by being either stretched, pinched, or cut. When it is understood that the nerve contains many bundles, each of which has a different specific function, then it is clear that one or all of these bundles may become partly or completely damaged depending upon the degree it is stretched, crushed, or divided. It is clear therefore that the nerve injury can result in a wide variety of circumstances, some of which can heal without any surgical intervention, and some that will require replacing the injured piece of the nerve with a new piece of nerve. In general, regardless of how long a time has passed from the time of an injury to a sensory nerve, it is possible to restore some degree of sensation to piece of denervated skin; the sensory receptors in the skin can be reinnervated even years after the injury to the nerve. In contrast, a muscle, the target end-organ of the motor system, loses its ability to be reinnervated by about one year after the injury. When the peripheral nerve regenerates, it does so at an average speed of one millimeter per day, which is about one inch per month. It is critical, therefore, for reconstruction of a nerve that has motor function to begin as soon as possible after injury. In situations where the time lapse has been too long to reinnervate the muscle, it may become necessary to reconstruct not only the nerve, with a new nerve, but also the muscle, with a muscle transfer or a microsurgical transplantation of a new muscle.

If a nerve is ***stretched***, it may simply recoil to its original length when the stretching force is released, or the nerve may snap completely, similar to what can happen to a rubber band. In general, a nerve can stretch about 6% of its length without changing its activity. But a stretch of more than 15% of its length will cause irreversible damage. For example, if the upper arm sustains a fracture of the humerus, then the radial nerve, which travels around the bone, can be stretched and completely stop working. This results in what is termed a "wrist drop". H the nerve has only been stretched, and not seriously bruised or torn, then, after the fracture is fixed, there may be complete return of radial nerve function by six weeks. With a more severe stretch, and some bruising, the radial nerve can still recover, but it may take about three months. Another example of a stretch injury is the birth of a baby in which the arm or face gets sufficient traction upon it so that the baby is born with a paralyzed arm and hand or a paralyzed face. For the facial paralysis associated with delivery, about 90% of the babies recover a good smile and facial function by the time they are one year old. The facial nerve begins in the brain and travels to the facial muscles, a distance that is not relatively long, and this is in favor of reinnervating the muscles. However, there is almost always some small degree of facial asymmetry, where one side of the face does not move exactly the same as the other. For the hand and arm, paralyzed at birth, there is often a great return of function by the first three months of age. The distance from the spinal cord to the muscle of the forearm and hand, in contrast to the distance to the facial muscles, is relatively long. This is against successful reinervation of those muscles.

Therefore, if motor function does not show good signs of recovery by three months after birth, then the nerves in the neck and shoulder region will require a surgical exploration. During surgery, it will be observed if the nerves are stretched and badly scarred, or actually pulled apart into two pieces. The type of nerve reconstruction may be extremely complicated. These examples illustrate the extremes of injury and recovery that may result from a stretch injury to a nerve. Quantitative sensory testing, with the **Pressure-Specified Sensory Device TM** is a non-painful method of obtaining measurements of sensory nerve function that can determine whether the injured nerve is recovering from the stretch injury.

If a nerve is **pinched or compressed**, the extent of sensory disturbance and loss of motor function depends upon how much pressure is applied to the nerve and for how long the nerve remained compressed. A common example is bumping the elbow at the "funny bone': This injury causes a brief pressure to the ulnar nerve and the sensory disturbance is perceived in the little finger, which is innervated by the ulnar nerve. The painful sensory disturbance is brief. If the bump were sufficiently hard to produce bruising or a fracture at the elbow, then the resultant swelling and subsequent scarring could result in a more severe degree of pressure being applied to the ulnar nerve. This could result in cubital tunnel syndrome, in which the little and ring finger become increasingly numb and sometimes cold, and there is progressive weakness and loss of co-ordination in the hand due to the important motor functions of the ulnar nerve. If the pressure continues upon the ulnar nerve in the cubital tunnel for sufficiently long, then sensation can be lost in the little finger and the muscle can degenerate causing a "claw hand" deformity. If surgery to remove the pressure on the ulnar nerve is done at the appropriate complete recovery can occur. If surgery is delayed sufficiently long, full hand function cannot be restored. Quantitative sensory testing, with the **Pressure-Specified Sensory Device TM** is a non-painful method of measuring the degree of nerve compression. This measurement, which can indicate whether the nerve has begun to degenerate, can help determine the most appropriate treatment for the nerve compression injury.

This measurement can be done for nerves in the leg and foot as well as in the hand, and is therefore useful in determining whether surgical intervention may be appropriate in the diabetic with symptoms of neuropathy.

If the nerve injury involves a complete or partial ***division of the nerve***, then there is an immediate loss of sensory and motor function related to the territory innervated by that nerve. The mechanism of the nerve division influences the results of the nerve reconstruction in that a different amount of nerve tissue will be damaged depending upon whether the nerve is divided by a cut from a knife or is tom apart by the blade of a 1/4 inch table saw. The amount of damaged nerve at the tom nerve endings cannot be known with certainty during the first three weeks after the nerve injury, so the surgeon must estimate how much of this tissue to remove. The scar that forms in any residual damaged nerve tissue that remains will prevent excellent nerve regeneration through that region. When the surgeon joins the two ends of the nerve back together, any tension that exists will tend to pull the two nerve ends apart. To prevent this, the body makes scar tissue in response to the tension. Again, this scar tissue will prevent excellent nerve regeneration. In order to reduce tension at the nerve repair site, the surgeon will put a new piece of nerve into the space to replace the original nerve portion that was damaged. This is called a nerve graft. Instead of a *nerve graft*, which must be obtained from another nerve in your own body, the surgeon may use a synthetic nerve guide called a *Neurotube*™.

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Nerve Reconstruction with a Graft or Neutrotube TM

In order to connect two ends of a nerve that is missing a piece of the original nerve, it is necessary to provide a method of joining the two ends so that scar tissue formation is minimized and the regenerating nerve fibers have some guidance as to the direction in which they should grow. The traditional approach is to take a piece of nerve from a sensory nerve in your own body, a ***nerve graft***, and transplant this nerve into the defect created by the injury. This nerve graft harvesting will create a scar in the area of your body from which the nerve is harvested, usually the back of your leg or your forearm. Since you lose a sensory nerve in this location, you will have an area without normal sensation in this nerve graft donor site. The end of the divided nerve in this site may become a source of pain to you, as it attempts to regenerate. These risks of nerve grafting are usually acceptable because the nerve being reconstructed is assumed to have some critical function for you, such as facial movement, or sensation in your thumb. The tissues within the nerve graft contain several factors considered critical for successful nerve regeneration. These are proteins that serve as railroad tracks to guide the direction of the nerve while regenerating and molecules called nerve growth factors that act as guidance signals for the regenerating nerve fibers. Connecting the nerve graft to the divided nerve ends is done using microsurgical techniques. In a large nerve, like the median nerve, which gives sensory function to many fingers and motor function as well, it is necessary to use several separate thin nerve grafts to reconstruct the larger nerve.

Because of the risks inherent in nerve grafting, it was desirable to provide an alternative method for reconstructing the nerve defect. Research has demonstrated that the body has the ability for a nerve to regenerate a distance of 3 centimeters or a little more than one inch without needing the special proteins and molecules found within a nerve graft. A nerve guide made from sugar and protein, called polyglycolic acid (PGA) is now available for this purpose. PGA is a substance that absorbable sutures have been made from since 1960. This is woven into a tube that is strong enough so that it does not collapse, and strong enough so that it does not lose its strength for 3 months. By the end of three months, the nerve which regenerates a one millimeter per day has grown through the guiding tube and out the other end to make its connection between the two ends of the nerve. This device is called the ***Neurotube***™. It was approved for use by the United States Government when a rigorous study demonstrated the results of nerve reconstruction were significantly better when a Neurotube™ was used than when the nerve ends were either directly sutured together or when the nerve gap was reconstructed with a nerve graft. If a Neurotube™ is used, then there is no nerve graft donor site scar, donor site sensory loss, or potential for nerve graft donor site pain. The two ends of the divided nerve are trimmed to remove damage tissue and then sutured using microsurgical technique into the two ends of the Neurotube ™ (Figures 2 and 3.).

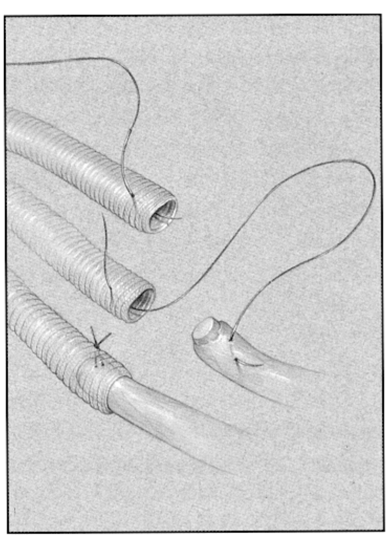
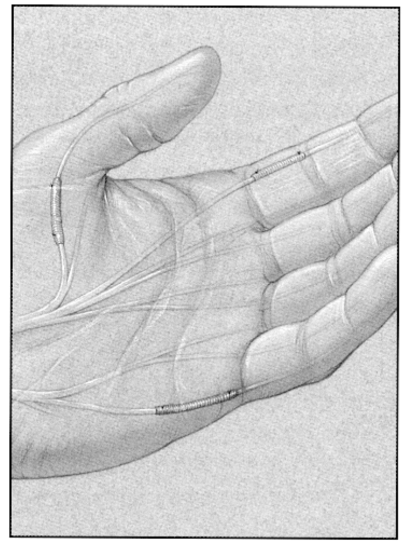


Figure 2. The Neurotube™ is a length of absorbable suture that is woven into a tube. The two ends of the injured nerve are place into the ends of the tube, and a new nerve is regenerated using the tube as a guide. The tube dissolves in about three months, after the nerve has completed its regeneration through the tube.

Figure 3. Example of the Neurotube™ placed in the hand.



Pain

Pain is related to nerve injury and to nerve reconstruction. When a divided sensory nerve attempts to regenerate and does so into an area of scar, then the nerve endings that normally tell the brain about pain, temperature, and touch get caught in the scar tissue. Any movement of that scar can set off a message to the brain that is interpreted as pain. Nerve endings stuck in scar tissue that send a pain message are called a painful ***neuroma***. Regardless of how much pain this one neuroma creates, the pain is always related to the region that the sensory nerve fibers originally innervated. When pain occurs after a nerve injury and the pain expands into many areas that are outside the distribution of a single nerve injury, then this pain can be given a different name. This pain may be called ***reflex sympathetic dystrophy*** (RSD) or ***complex regional pain syndrome*** (CRPS) or ***sympathetically maintained pain*** (SMP) .This condition is not just one of pain, but is associated with over activity of the sympathetic nervous system, so that the area of pain is a different color, like pink or purple, and is usually a different temperature, like cooler, than the surrounding non-painful skin. The painful area is often sweaty, swollen, and stiff. It is possible for several sensory nerves to be either involved in neuroma formation or be compressed in the injured area, and for the combined areas of these several nerves to give the diffuse pain usually associated with RSD, even when the other features of RSD are not present. It may be difficult for doctors to distinguish these situations.

Treatment of pain of neural origin requires correct diagnosis as to which nerve is involved in the pain mechanism, and as to whether there is a neuroma present or a compressed nerve or both. This decision often requires that the supposed painful nerves are briefly put to sleep by injecting them with a local anesthetic, like xylocaine or marcaine. Your response to these *nerve blocks* will determine subsequent treatment for the pain. When these nerve blocks are done to the sympathetic nerve fibers in your neck to evaluate the presence of *sympathetically maintained pain*, then they are called a *stellate ganglion block*. If they are done to evaluate the sympathetic system in the leg, then they are called a *lumbar sympathetic block*. This local anesthetic can be infused for a prolonged period of time to treat lower extremity pain through a catheter placed near the spinal canal, called an *indwelling epidural catheter*.

Prior to surgery, attempts to treat the pain should be tried that include desensitization, scar massage, steroid creams, steroid injections, transcutaneous electrical stimulation, and certain medication. These medications include non-steroidal anti-inflammatory agents, like advil, ultram, celebrex or viox, and the newer group of drugs for neuropathic pain like dilantin, tegretol, elavil, and neurontin. None of these are narcotics. Some pain specialists may prescribe long acting narcotics for severe pain that seems to have no other treatment available for pain relief, but this approach can produce drug addiction.

If putting a non-critical sensory nerve to sleep eliminates your pain, than the neuroma on that nerve can be removed, trading a numb or anesthetic region for the painful region. Sometimes several nerves must be removed. This is the approach taken for a painful knee or a painful area of the hand or the top of the foot. Since the cell body for the resected neuroma is still alive, in the dorsal root ganglion, next to the spinal cord, this nerve will attempt to regenerate, just as if the nerve had been repaired. In order to minimize the chance for the regeneration to result in another painful ***neuroma***, the end of the nerve is placed loosely into an area away from joint movement, away from tension, and into an environment that has no degenerating sensory nerve fibers, such as a normal muscle. If this new hiding place in the muscle is directly hit, the pain may come back, but these nerve endings cannot regrow into the original injured area. Within the injured area, some sensation may be recovered by ingrowth of normal nerve fibers from the adjacent normal skin. This protective mechanism is called collateral sprouting, and may, on its own, produce some disturbing sensations for a few months.

The usual events associated with normal nerve regeneration can be painful. As the regenerating ends of the nerve, called sprouts, travel, they make contact with each other and with structural proteins. The neural impulses generated by this activity may be interpreted by your brain as pain. It should be expected that for the time period associated with nerve regeneration there may be pain sufficient to need therapy and/or pain medication. Just understanding that this is expected to occur, and is "good pain'; or pain for a good reason, is enough to help many people adjust to its presence. Some patients may need much more than this reassurance, and Quantitative Sensory Testing with the **Pressure-Specified Sensory Device TM** can document this nerve regeneration. Therapy to enable the brain to reorganize to these new neural inputs is called sensory re-education. A program of sensory re-education can be provided for you by your doctor or a therapist.

Other brochures in this series:

- Knee Denervation
- Carpal Tunnel Syndrome
- Cubital Tunnel Syndrome
- Radial Nerve Entrapment Syndrome
- Restore Sensation and Strength to Your Hands and Feet
- Tarsal Tunnel Syndrome
- Thoracic Outlet Syndrome

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