The Paralysis Center
PATIENT GUIDE

# Brachial Plexus Injury

## *Reversing Paralysis & Restoring Function*

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# 1. Introduction

*If you are a patient who has suffered injury to your brachial plexus, we are battling against time.*

*Please do not wait to see what kind of function may or may not return following your injury, no matter what you may have been told. More than any other nerve injury, repairing a brachial plexus injury is the most complex* ***and the most time-sensitive of any peripheral nerve injury****.*

*We have the greatest chance of restoring maximum function to your arm and hand the faster you can be seen by a* ***Brachial Plexus Specialist*** *- ideally within the first six months following your injury. If this is you, please book a consult immediately with a Brachial Plexus specialist.*

*In 2017, in partnership with Massachusetts General Hospital, Harvard Medical School, and the Spaulding Rehabilitation Hospital, we founded the Paralysis Center - a world-class patient treatment and medical research center for all forms of paralysis.*

*Because we treat a significant number of brachial plexus injuries, we've been able to develop some of the most advanced diagnostic protocols and surgical strategies available today. These innovative techniques are providing real results for patients in reversing paralysis and restoring function, and we're helping to educate our medical colleagues around the world by sharing our knowledge.*

*To maximize your chances of recovery, and because brachial plexus injuries are so complex, you're going to require the expertise of paralysis specialists across several disciplines. From diagnostic evaluation to surgery, to post-surgical rehabilitation, you're going to need a team of specialists working together with you.*

*I realize there is a great deal of information for you to absorb about your injury and the options available. It's also very difficult to find up-to-date and medically accurate information about the best way to treat brachial plexus injuries. That's why we've written this patient guide to help you. In the following pages, I will take you through the anatomy of a brachial plexus injury and explain everything to you as I would if you were a first time patient seeing me in my office. We'll discuss what to expect when you see your specialist and the surgical options that may be available to you.*

*This patient guide is written for anyone who has suffered from a brachial plexus injury or whose loved one has suffered from a brachial plexus injury.*

*Brachial Plexus injuries can result from a number of different causes but are usually the result of some kind of trauma - most commonly motorcycle accidents or snowmobile accidents where the rider is flung from their vehicle and lands with a shoulder striking the ground. The shoulder is pulled forcefully away from the neck causing a tearing or rupture of the nerves.*

*No matter how your brachial plexus injury occurred, you may be hoping it will heal on its own. You may have tried rest, physical therapy and medications to alleviate your condition. You may have been told that there is nothing that can be done to treat your paralysis (not true). You probably find yourself with many more questions than answers.*

*I hope this guide answers all your questions – but if it doesn't, at the end of this book I've provided you with a way to contact me.*

*We have a lot of ground to cover, let's get started.*

Justin M. Brown M.D.
*Director & Founder*
The Paralysis Center

## 2. The Anatomy of a Damaged Nerve

When a nerve injury occurs, it's important to understand the anatomy of a nerve and specifically what function the damaged nerve plays in the movement of a specific part of your body.

A nerve is essentially a cable, much like the coaxial cable that you plug into the back of your television. It is designed to carry information from one point to another. If you take a pair of scissors and cut a cable in half, you'll see that the inside is made up of many smaller wires. A nerve is the same - it's made up of all kinds of little sub-nerves, or "fascicles", and within each of those is the smallest unit, known as an *axon*.

An axon is a long, thread-like process of a nerve cell which acts like a wire to conduct electricity to its target. Each axon is designed to carry information rapidly between the brain and the body and back. In order for it to convey that information effectively, just like a wire, it requires insulation. In this case the insulation is called *Myelin*. Myelin is provided by a cell called the "Schwann cell" that wraps itself around the axon until it is perfectly insulted to send its impulse effectively. Wherever an axon is, there must be Schwann cells. They are partners and cannot function without each other

When we're talking about muscle function, the axon that causes it to move is a process of a cell located within the spinal cord called the *motor neuron*. This motor neuron extends its axon through the peripheral nerves, all the way down to make a connection with a group of muscle fibers. Anytime the motor neuron within the spinal cord is activated, it sends the signal all the way down this pathway to the muscle fiber that it innervates, causing them to contract.

Similarly, there are also sensory fibers whose cell body is located in what's called the spinal or *dorsal root ganglia.* These ganglia are groups of neurons that live in the nerve root just outside of the spinal cord. The sensory fibers of these neurons extend from this ganglion in two directions. They extend away from the spinal cord to the skin and other sensory organs in order to gather information about touch as well as other types of sensation. These ganglion cells also send an axon to the central nervous system so that the sensations perceived are conveyed to the brain and we thus become aware of that touch.

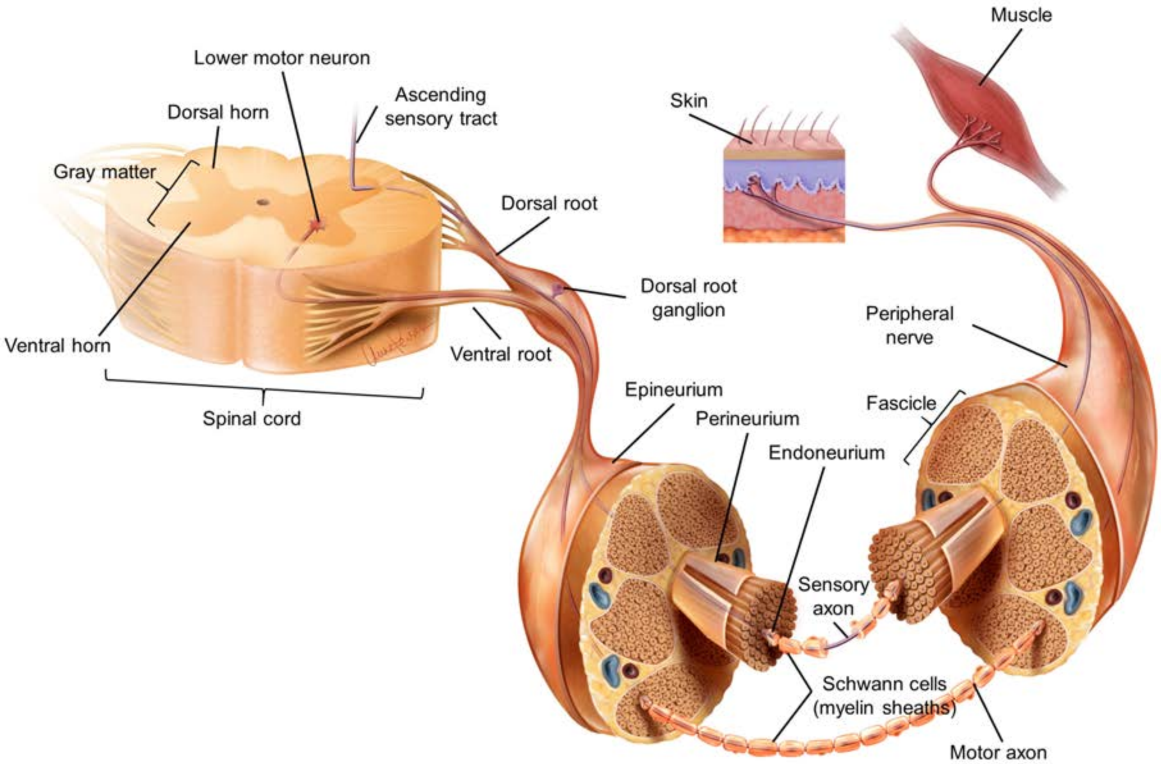



Figure 1. Anatomy of a nerve: from spinal cord to skin and muscle.

When an axon is severed, that communication pathway is disrupted. The portion of that axon that is still connected to its cell body (in the spinal cord or dorsal root ganglion) remains intact and it begins to shift from this conducting mode, where it's conveying information as usual, to a regeneration mode, in which it stops sending impulses and begins to regenerate or grow from the cut end, attempting to once again establish a useful connection.

At the same time, the portion of the axon that is now separated from its cell body cannot survive any longer. This portion essentially disintegrates over several days in a process called "Wallerian Degeneration." The Schwann cells participate in this process, clearing the debris and preparing to receive a new axon. They also transition to a regeneration mode in which they line up to receive a new axon and begin to produce chemicals which attract regenerating axons. These chemicals are called neurotrophic factors.

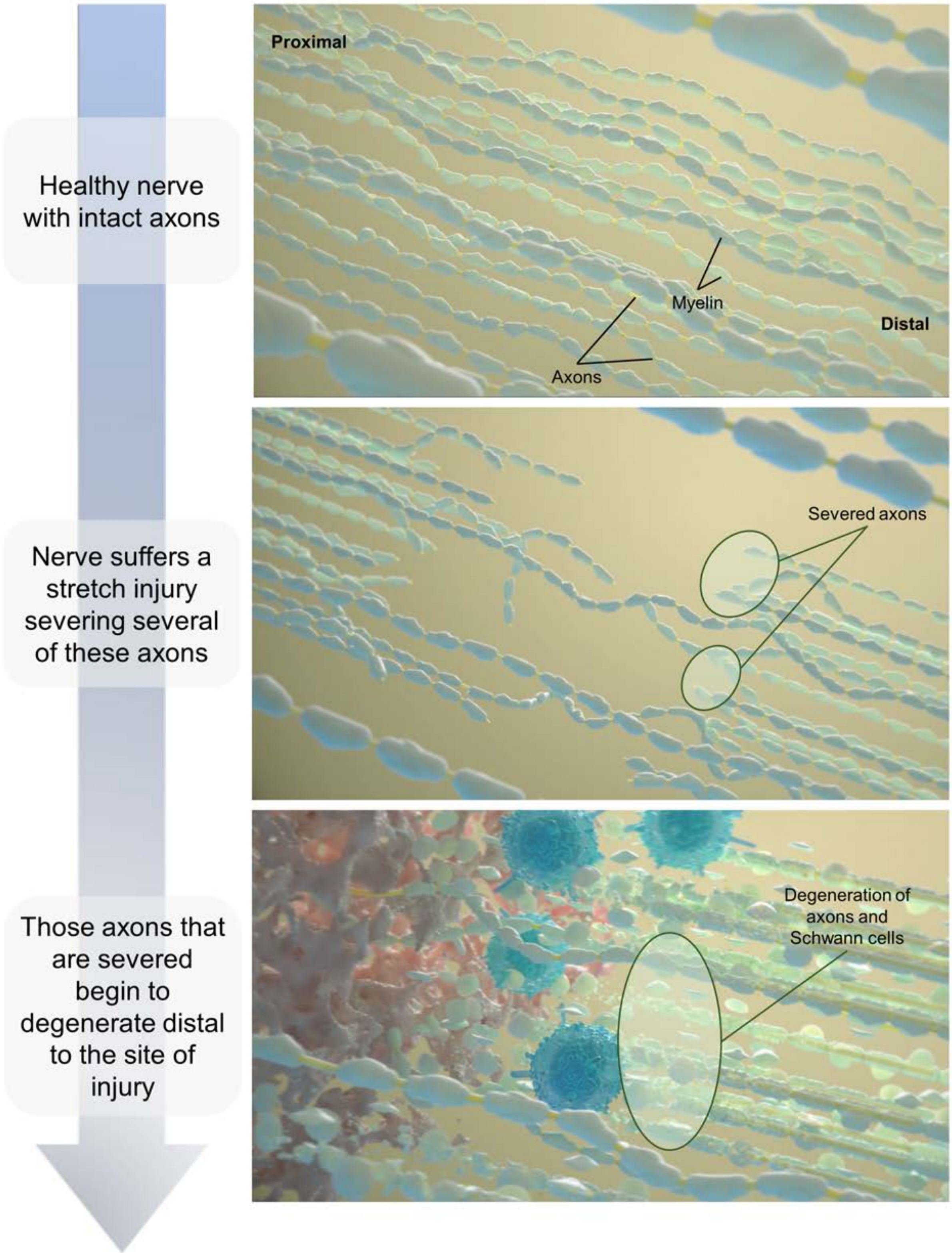



Figure 2. Divided Axons and Wallerian Degeneration

The cut ends of each proximal axon (that are still attached to their cell body) send out little neurites, or multiple tiny axons, from the end of each cut axon.  Like a cut limb of a tree, sprouting new branches. These will reach out looking for an appropriate target.  If they can find the chemicals being produced by the Schwann cells, they will follow those to the Schwann cells. These cells are waiting to receive the new axon and to help direct it to an appropriate target.

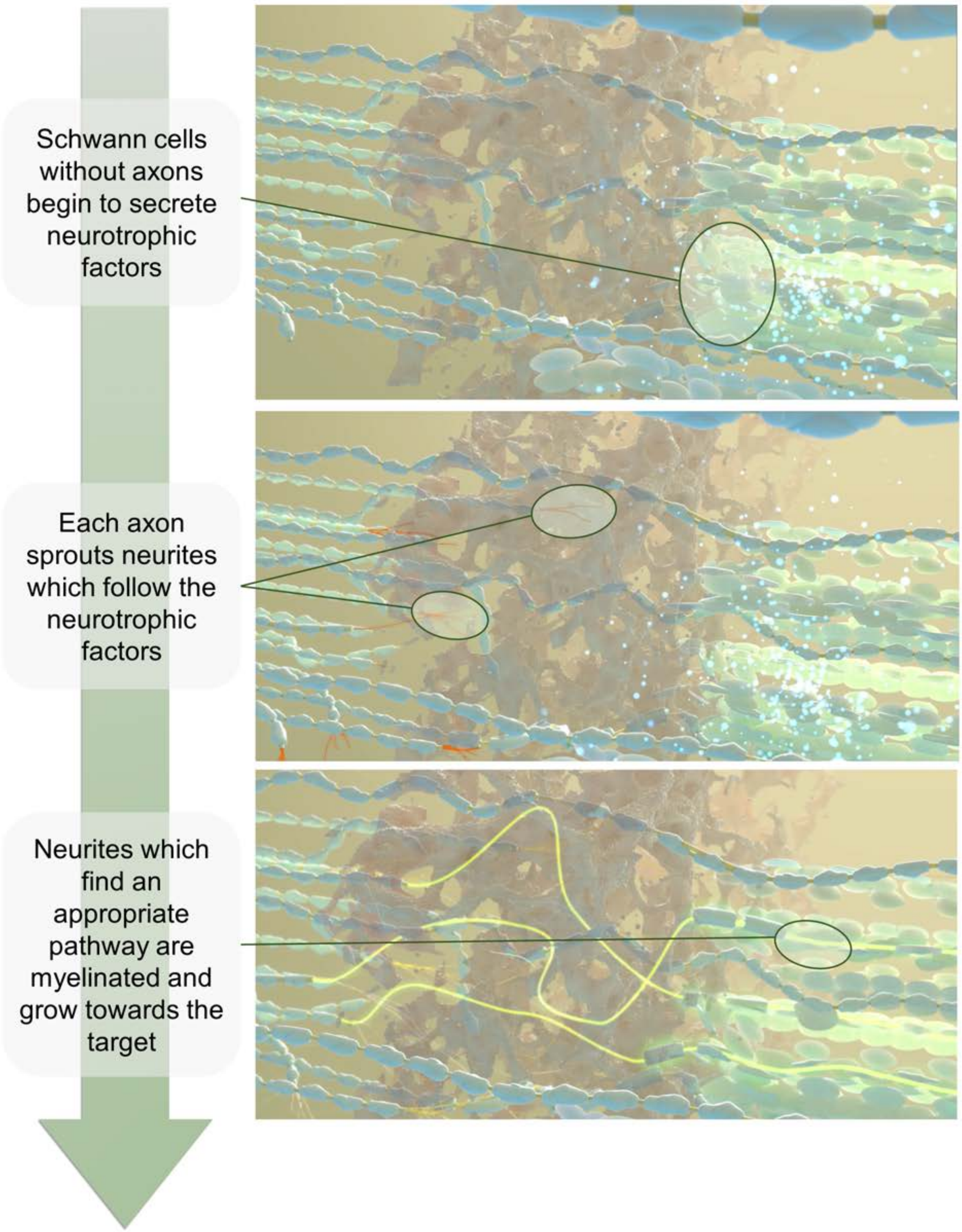



Figure 3. NT factors and axon regeneration

Patients often ask me, “So if my nerve is like a coaxial cable, can’t you just splice the wires back together and get immediate function?” Unfortunately, we can’t. The end of the nerve that connects to the paralyzed muscle but is now separated from the spinal cord actually degrades and goes away completely. There is no longer a “wire” between the cut point of the nerve and its muscle to splice to. Awakening a paralyzed muscle requires regrowth from the site of the injury all the way to that muscle. Depending on the distance, the journey can be quite long!

If the pathway for the nerve to reach the muscle is no longer intact, surgery is required to restore that pathway. If we can suture a muscle that has axons to the one that has lost its axons, those neurites can follow the scent of those neurotrophic factors emanating from the Schwann cells in the distal nerve. Then they can grow back through that nerve down to the muscles. If the axons reach them in time, the muscles can then begin to contract once again.

This nerve regeneration process takes a very long time - nerves grow at a rate of about 1mm per day, or 1 inch per month. If we’ve done a perfect repair from its site to the muscle, we can measure off and have a good idea of how long it will take for that muscle to begin to contract again – typically somewhere between 4 months and 1 year, but some repairs take even longer.

The next question to ask is how much movement can be restored? This depends on many factors. For example, our chances of success are best if we operate earlier, if we make a connection closer to the target muscle, and if we can use a nerve with a large number of axons. It also makes a big difference if the patient works with us to achieve our optimal, desired goals. It is important to avoid nicotine products of any kind (even a nicotine patch will hinder axon growth). This is because regeneration requires the development of small blood vessels to supply nutrients to those growing neurites. If they don’t have an adequate blood supply, they don’t grow well and nicotine definitely hinders the blood supply development. Also, exercising or activating the nerves that were transferred helps signal them to grow. Finally, it is crucial to ensure that the joints involved do not get stiff while we await recovery. Sometimes we can achieve excellent nerve growth, but the recovery is quite poor simply because the arm and hand have become “stuck” and difficult to move due to inadequate patient effort to maintain them. Therapy is critical!

## 3. Assessing Nerve Damage

Not all nerve injuries are the same. Just as with other injuries, there are degrees or severities of injury. Some injuries recover completely. Other injuries recover incompletely, and still others will not recover at all.

In diagnosing the degree of your nerve injury, we use a classification system known as the “Seddon’s Classification System”. Sir Herbert Seddon, an orthopedic surgeon who treated peripheral nerve injuries in World War II, published a paper in 1943 describing 3 types of injuries that result in loss of function.

### ***Seddon’s Classification System***

#### *Neurapraxia*

The first type of nerve injury is one in which the axon remains intact and connected to the muscle, but the muscle does not receive the signal and does not function. This is because there is a conduction block. Something is not allowing the signal to travel down the axon to activate the muscle. This type of injury is referred to as a *neurapraxia* and is the least severe nerve injury type. Neurapraxia can be the result of a stretch injury, compression of the nerve, or poor blood flow. In the case of neurapraxia, the axons lose their myelin (their insulation). Remember, that is the insulation provided by the Schwann cells as they wrap the axons. Even though the axons are present – they just can’t get the muscle to contract because the signal can’t bypass the missing myelin. The Schwann cells need to wrap their myelin back around the axon, which can take 3-4 months in the case of a serious injury. The good news is that once the myelin has regenerated and the insulation is restored, the muscle function can be just as good as it was originally - the patient gets full strength recovery!

The only time that surgery is required for neurapraxia, is if something is continuing to compress the nerve – for example, if there’s scar tissue pressing on the nerve. Once surgery has removed the compression, the nerve is relieved of this compression and blood flow is restored. From that point on, the axons begin to “wake up” and function as the myelin insulation grows back.

#### *Axonotmesis*

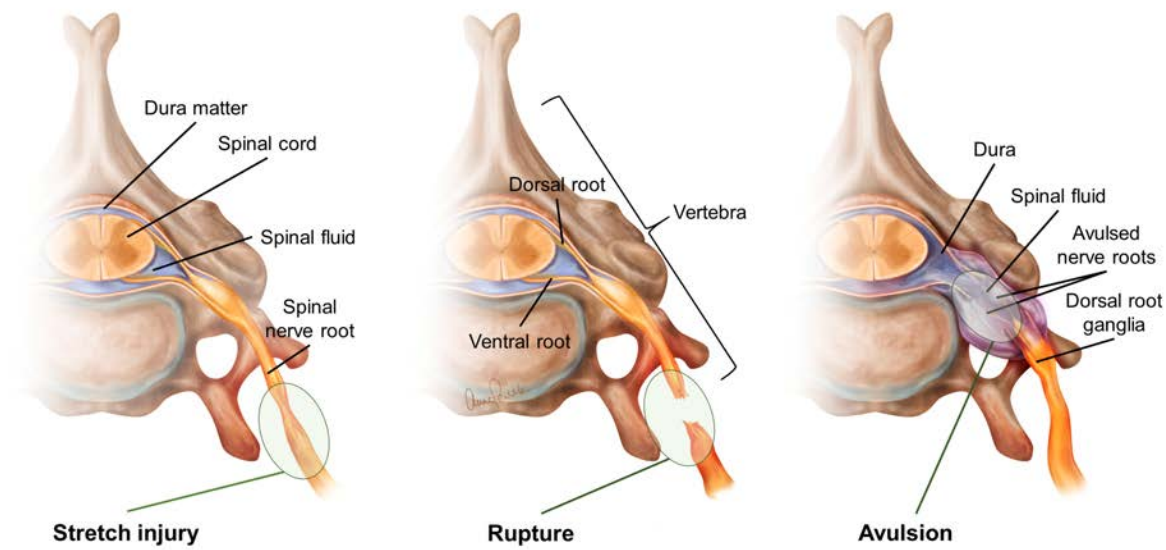
The next type of nerve injury is known as *Axonotmesis.* This simply means that instead of just the insulation getting damaged, those axons are cut in half – the nerve was crushed so much that the axons are severed at that location. The nerve that they reside in – “the cable” – may appear intact, but within it the wires are cut and the associated muscles are paralyzed and skin has lost its sensation. The only way they are going to function again is by growing down distally (away from the spinal cord) from the point that they are cut to reach the muscle once again. This process can take many months given that the rate of growth is about 1mm per day, depending on the distance of the injury from the muscle.

#### *Neurotmesis*

*The third nerve injury classification is called Neurotmesis*, which simply means that the entire nerve, the whole “cable” with all of its axons, is cut. In neurotmesis, the nerve and its connective tissues are completely severed. Often this type of injury can be identified on an MRI. When this happens, the nerve cannot recover unless it is reconnected surgically.

There are actually two types of neurotmesis or severed nerve injuries.

- *Rupture* – A rupture occurs when the nerve *outside of the spine* is torn in two. This injury requires a surgical repair to restore the connection so that the axons can grow from the cut point back to the muscle.
- *Avulsion* – An avulsion occurs when the nerve root is literally plucked directly out of the spinal cord. In this case, we no longer have available axons to direct to the paralyzed muscles that were previously supplied by this nerve. There has been research into the concept of being able to plug the nerve back into the spinal cord by making a cut in the cord itself and trying to reinsert the nerve. Results have been poor and this is a relatively dangerous procedure, so we do not recommend it at the Paralysis Center. But that doesn't mean that there is no hope for that muscle or nerve to work again. It merely means that we have to go to another source (a different nerve) for the axons that we need – and that's the origin of the *nerve transfer concept*. When we do a nerve transfer, we cut a healthy, functioning nerve and suture it to the paralyzed nerve, so that its axons will now grow down that pathway to recover the paralyzed muscle.




Types of injuries to the brachial plexus. A stretch injury will usually contain some degree of axotomy and can represent a Sunderland 2nd, 3rd, or 4$^{th}$ degree injury. Rupture and avulsion injuries are Neurotmetic injuries and represent Sunderland 5$^{th}$ degree injuries.

To summarize, using Seddon's Classification System, the only nerve injury that we absolutely know we'll have to repair is the third classification, neurotmesis. Classification number one, neurapraxia, is the conduction block. Classification number two, Axonotmesis, tells us axons are cut, but here's where things get a bit more complicated.

Seddon's Classification System doesn't tell us anything about the ***architecture of the nerves***. If the architecture of the nerve is perfect, it should grow back without a problem. If however the nerve architecture has been disrupted, then there might be incomplete growth - or no regrowth at all.

### *Sunderland Classification System*

As we discussed above, we need to know more about the architecture of the injured nerves. That's why we also use a second classification system called the "Sunderland" classification system.

This system has five degrees of injury.

Sunderland's neurapraxia is exactly the same as Seddon's 1$^{st}$ degree injury..

Sunderland's 2$^{nd}$ degree injury corresponds with axotomy, but with the surrounding nerve architecture intact. The axons are going to grow back but as we know the growth is slow. So while the patient should fully recover, it takes a very long time to get there. Again, that delay in recovery is the result of the 1mm per day growth rate.

Sunderland's 3$^{rd}$ degree injury presents an ambiguous injury. The architecture of the nerve has been partially disrupted and probably some axons can make their way through the scarred tissue and through the disrupted nerve architecture and out the other side - but not all of them. It is this type of injury that a paralysis neurosurgeon necessarily will spend most time focused on. We have to decide, is this a number 3 that's going to recover well? Or, is this a number 3 that's not going to make an adequate recovery, and, requires removal of the scarred segment and starting over?

Sunderland's 4$^{th}$ degree injury is what we call a *neuroma-in-continuity*. This term means that even though the nerve looks like it's still connected, the inside of the nerve has been so disrupted that it has been completely replaced with scar tissue. No axons will ever make their way across this barrier of scar within the nerve. This situation absolutely requires surgery to remove that impenetrable barrier.

Sunderland's number 5 is the same as Seddon's neurotmesis – the nerve is completely divided and must be surgically repaired.

So, in summary, first and 5$^{th}$ degree injuries are relatively clear in their management. The big job of reconstructive neurosurgeons, then, is to determine if the injury that is more severe than a first degree, but clearly is not divided, is a Sunderland classification 2, 3 or 4 and how best to treat it. *Is this a nerve injury that is capable of recovering, or not?*

***The distinction is critical.***

If there is some recovery - even if very slow - surgery may not be required. If there is no recovery, surgery may be the next best step.

### *Time……..Early Intervention is Vital*

The other complicating issue with these injuries is that the longer a patient waits to do surgery, the poorer the likely results. Particularly for brachial plexus injuries, the best results are obtained when surgery occurs within three months**.** After a year, the results will be impaired and much less reliable.

For most patients, six months is usually an acceptable compromise. That time period gives us a narrow time window to test and determine whether we have a second, third or fourth degree injury on the Sunderland scale. Again, given enough time, is the nerve going to recover or not? This key determination makes comprehensive testing necessary.

This is a good point to talk about the consult process and what you can expect.

When a patient presents for evaluation, the first step is a comprehensive physical examination and review of any patient imaging studies that have been done. We then assess whether we believe the injury has the potential to recover naturally or will require surgery. Because a physical examination cannot tell us everything about a muscle's functioning, EMG/NCS studies are also performed. Typically there are specific muscles and nerves we are interested in testing to better define the type of injury that has been incurred.

If there is a reasonable chance of recovery – for example the imaging seems to show nerves that are neither avulsed from the spinal cord nor ruptured – we will repeat the evaluation in 4-6 weeks to look for improvement in the examination and EMG testing. These interval tests are the best method we have of demonstrating early recovery of a nerve. No indicated progress on these interval studies usually leads us to recommend surgery.

Later in this guide we discuss the diagnostic testing, and why pinpointing an accurate diagnosis is so critical, but first it's essential for you to understand the anatomy of the brachial plexus and how injuries are caused.

# 4. Understanding Brachial Plexus Anatomy

***What Is the Brachial Plexus?***

The brachial plexus describes the nerves that emanate from the cervical spine between the C4 and T2 vertebral bodies and provides function to all of the muscles of the arm and sensation to the entire limb.

Emerging from five 5 nerve roots – C5, C6, C7, C8 and T1 – these nerves reach from the cervical spinal cord to provide all of the functions of the arm and hand.

This physical complex is called the brachial "plexus" because these nerves interweave with one another (plexus means a network of interlacing nerves or blood vessels).

- C5 and C6 join to form the upper trunk
- C8 and T1 join to form the lower trunk
- C7 becomes the middle trunk
- Each of those trunks then divides to form anterior to posterior divisions.
- Those anterior and posterior divisions join with other anterior and posterior divisions, forming 3 cords.
- The cords divide into separate nerve branches that together make up the major peripheral nerves of the upper extremity.

We have an *axillary nerve* that goes to the shoulder muscle and the *suprascapular nerve* which provides function to the muscles of the shoulder blade. Together these nerves and muscles bring the arm up to the side and turn the shoulder out.

The *musculocutaneous nerve* flexes the elbow.

The *pectoral nerves* make the chest muscles move, as with performing a push up.

The *radial nerve* is responsible for all reaching movements of the arm – extending at the elbow with the triceps, extending the wrist and opening the hand.

The *median and ulnar nerves* cause the hand to close and provide the fine motor function of the fingers.

These nerves and others work together to also provide feeling to the arm, hand, and fingers.

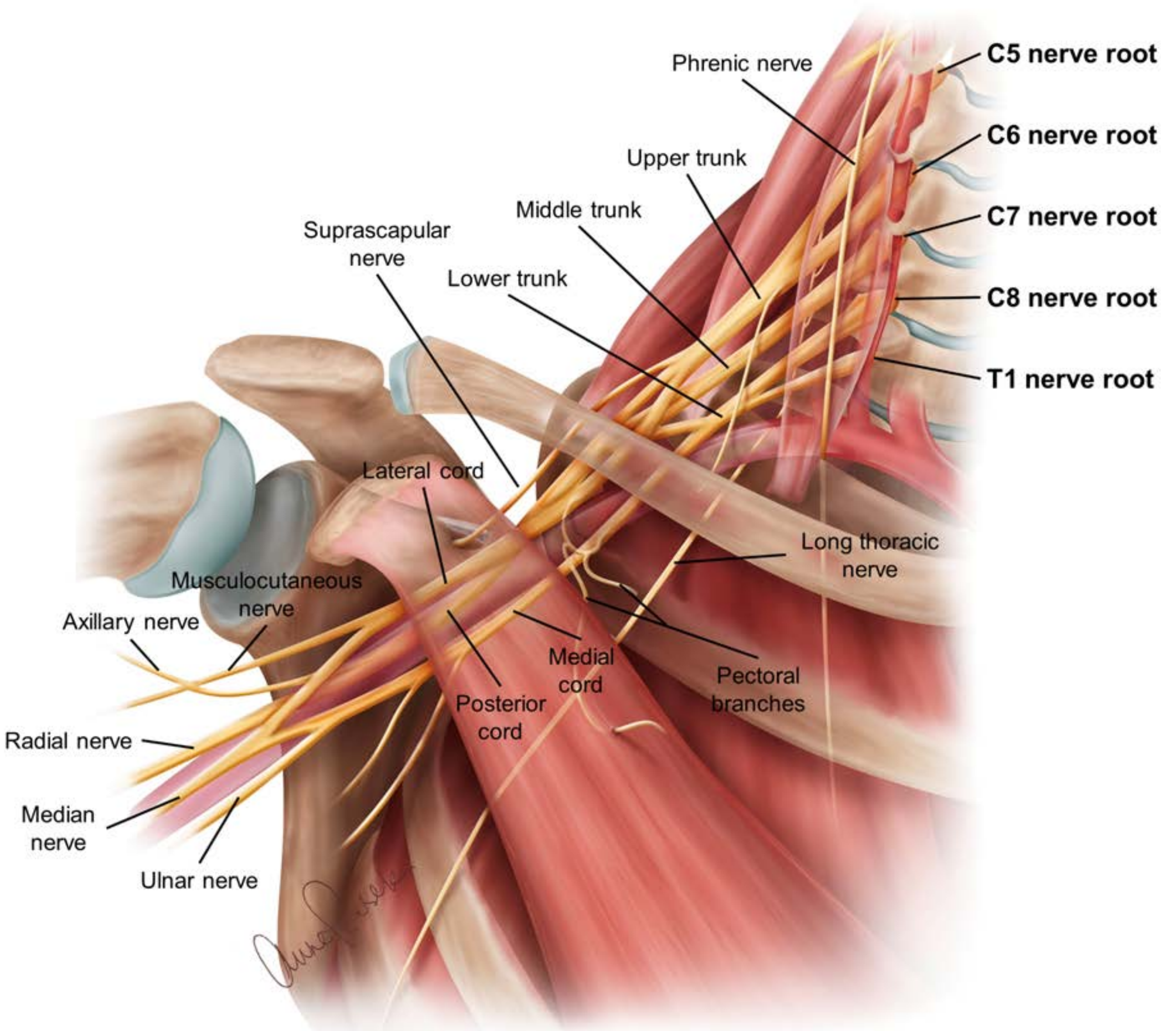



Figure 4. The brachial plexus: Made up of 5 nerve roots and provides all of the major nerves of the arm.

Injury to any of these nerves can result in partial or complete paralysis, as well as partial or complete loss of sensation. In the most severe brachial plexus injuries, the arm can lose all motor function and all sensation. It will simply hang limp at the side.

## 5. Diagnosing Brachial Plexus Injuries

Injuries to the brachial plexus are typically the result of trauma, tumors, illness or inflammatory processes.

The most common cause of brachial plexus injury is trauma to the shoulder/arm due to motorcycle, ATV or snowmobile accidents, or a comparable fall. The force of impact causes the shoulder to pull away from the neck, stretching or tearing the nerves. Injuring these nerves causes them to lose their connection to the muscles and skin that they innervate, resulting in partial or complete loss of arm function. Because young men engage in these, often more high-impact, high-risk activities, the majority of brachial plexus patients we treat are young men aged 16-30. Anyone involved in a violent crash or other, similar accident is at risk of this type of injury.

Brachial plexus injury can also occur with a difficult childbirth. Sometimes, during a difficult vaginal birth, the baby's shoulder can be difficult to deliver while passing through the birth canal. This requires some force by which, again, the neck is pulled away from the shoulder stretching those nerves in order to effectively deliver the child.

Injury to the brachial plexus can also be caused by unusual sources. There are inflammatory disorders such as neuralgic amyotrophy (or "Parsonage Turner Syndrome") in which the arm will develop excruciating pain and then certain muscles become weak or paralyzed. Most such patients recover, given enough time, but don't. This is an injury of the brachial plexus, and when it doesn't heal, we'll treat it the same way we treat other such injuries.

Tumors, radiation, degenerative spinal disorders, and even complications from other surgical procedures can also injure brachial plexus nerves. When we can halt the source that's causing injury, we can usually provide better function with surgical reconstruction.

With nerve injuries, patients can typically experience a number of symptoms including:

- Paresthesia (a sensation of buzzing or tingling)
- Radiating pain
- Muscle weakness or paralysis
- Numbness and loss of sensation
- Complete paralysis of the arm - sometimes referred to as flail limb - can occur with the most severe injuries

Brachial plexus injuries are often categorized according to the part of the brachial plexus that is affected:

*Upper Plexus Injury*

- Caused by a forceful downward traction on the shoulder, as can occur with a sudden, violent impact from a motor vehicle accident;
- Typically injures the C5 and C6 nerve roots of the upper trunk, sometimes C7 as well;
- Loss of all shoulder function with no ability to move the arm up to the side is typical. The patient can usually still shrug their shoulder because that muscle (the trapezius) is controlled by the spinal accessory nerve which comes from the skull base;

- Loss of the ability to bend the arm at the elbow (biceps function) is also common. There may also be weakness of the triceps muscle and wrist extensors, but the hand usually still works quite well; and,
- Numbness and tingling of the lateral arm, forearm and first 2-3 fingers is common (and referred to as "Erb's Palsy" in infants).

*Lower Plexus Injury*

- Caused due to a sudden, violent upward pull of the arm overhead;
- Injures the C8 and T1 nerve roots of the lower trunk, sometimes C7;and
- Results in loss of hand function as well as loss of feeling along the ulnar border of the forearm and hand (the last 2-3 fingers, - referred to as "Klumpke's Paralysis in infants).

*Complete or Global Plexus Injury*

- This is the most severe brachial plexus injury;
- Damage to all roots and typically a combination of avulsions and ruptures, but occasionally all roots are avulsed;
- Total loss of movement and sensation in the extremity where the arm hangs limp at the side;
- Usually the patient can still shrug the shoulder and will have some feeling in the armpit, but the rest of the arm is non-functional; and,
- The most difficult brachial plexus injury to repair

So now we've discussed the anatomy of a nerve, the various classifications of nerve injury, what the brachial plexus is, and how various brachial plexus injuries occur~~s~~.

Now let's move on to discuss the various diagnostic tests we use to properly assess nerve damage, and, why getting an accurate diagnosis of your nerve injury is so important.

## Nerve Conduction & Diagnostic Studies

### *The Importance of a Correct Diagnosis*

Brachial plexus injuries are complex and require a very specific diagnostic protocol. Of course, any physician can make the diagnosis. However, physicians who don't see this type of injury very often may not have the best diagnostics available to them in order to gather the information that is most critical to planning an intervention. That's why seeing a specialist who routinely treats brachial plexus injuries is imperative.  For example, most centers have MRI capability and have what's called a "brachial plexus protocol."  If they do not have a specialist who makes surgical decisions based upon that MRI, it is likely that the images will not be good enough for surgical decision making.  At our clinic we frequently have to repeat MRI's that were done at other (often very reputable) centers.  This is true with EMG studies as well.  If the neurologists do not work with a brachial plexus surgeon regularly, they may not understand the specific injury issues presented. Again, at the Paralysis Center we typically have to repeat the entire EMG/NCS study so that all remedial issues and intervention questions most pertinent to the planned reconstruction have been addressed.

An important aspect of determining optimal treatment of a nerve injury is to look at the injury in its present state, its complete physiological history, and how its condition may have changed over time.

Why is this important? Because we know that axons regrow at a predictable rate and pattern. They progress very slowly from proximal (closest to the point of attachment) to distal (farthest away from attachment point) at the rate we discussed earlier: about 1mm per day.

When getting MRI studies, we are trying to identify divided nerves that cannot recover (ruptured or avulsed) as well as nerves that remain in continuity that therefore might recover.  With our EMG's we are looking specifically at those nerves that might recover and seeing if we can find evidence of early signs of that recovery.  If all nerves are divided, we can proceed to surgery.  If critical nerves appear connected on the MRI, we proceed more cautiously, hoping for signs that they will recover on their own.

In the latter case, after getting a baseline assessment, studies can be done again in 4-6 weeks to check for any progress made. If suddenly a follow-up EMG shows another motor unit in the next muscle group, we have evidence that the axons are regenerating and recovery is in process. This scenario means that surgery for these nerves may not be called for.  We can step back and let the natural recovery process continue.

At the Paralysis Center, we have a team of specialists with protocols in place to gather all of the data necessary to make the best treatment recommendations possible. Better data means better decisions. Better decisions mean better patient outcomes.

Now, I'm going to walk you through our diagnostic testing...

## Diagnostic Testing

During an evaluation, a patient will likely undergo several tests to examine and determine the degree of functioning in the affected areas.  The results of these tests will guide the treatment options available.

- *Physical Exam* – A detailed physical exam is first performed to see if there is muscle movement and whether there has been any change in that muscle movement (more or less) in recent weeks.  If the muscle moves at all, typically there is a reasonable chance that it will recover.

- *MRI* – An MRI will give the best picture of the affected nerves to determine whether those nerves are connected or divided.  "Divided" can refer to a rupture where the nerve has a missing segment because it has been pulled apart (an avulsion);or,the nerve root has been torn away from the spinal cord.  Even when nerves still appear to be connected, MRI's can also sometimes reveal how thickened and scarred the injured nerves are, which can provide further information about the extent of injury and likelihood of recovery.

Fig. 5. An MRI machine has a large tube that you rest inside while images of your nerves are obtained.

- *Electromyogram (EMG)* – Think of an EMG as comparable to inserting a microphone into a muscle. In this test, we place a needle into the affected muscle to look for muscle responses, called *motor units,* and also what's called *spontaneous activity*. Spontaneous activity is electrical activity in the muscle that indicates that it has recently lost axons. Muscles and nerves support one another and when that support is removed – in this case by the loss of one or more axons - the muscle membrane becomes hyper-sensitized and will begin to activate on its own - or - with very little stimulus.

  Muscle response is measured in *motor units*. When muscles are weak, even when muscle movement is undetectable on examination, movement may still be present. The EMG can detect tiny motor responses. If only a very few axons are present, we can usually see motor units – evidence that there is "life" in the muscle and potential for recovery. EMG's may be repeated in a few weeks to check whether function is increasing, with more motor units being identified, or remaining unchanged. Changes over time are followed closely to decide whether muscle recovery will progress to the point of useful function, or, will stop early and therefore require surgery to get the best possible result.

- *Nerve Conduction* – A nerve conduction procedure involves essentially sending electrical current up and down the nerve to observe its responses. Nerve conduction studies can tell us whether there are functioning axons present and whether there is a conduction blockage due to a neurapraxia (see above). If the stimulation makes the muscle move when a patient can't make it move, axons are present. Under these circumstances, there is probably myelin damage and a conduction problem.

  Sensory nerve conductions can be particularly helpful in identifying an avulsion, which is typically difficult to diagnose. Although avulsions are often very clear on MRI's, sometimes they are harder to detect.  In those cases, we need more evidence. If we can still stimulate sensory conductions up and down a patient's injured arm, but the patient has no feeling, it is highly likely that the affected nerve is *avulsed*. As we discussed earlier, while the cell bodies of the motor axons reside inside the spinal cord, the cell bodies of the *sensory axons* are located in the nerve root just outside the spinal cord, in the dorsal root ganglion. So if a nerve is pulled directly out of the spinal cord, the cell bodies are still there and their axons still make connection from that cell body all the way through to the skin. But since they're pulled away from the spinal cord, they can no longer communicate with the brain. That is why they still are able to conduct, but provide no feeling to the patient's arm.

Once a paralysis specialist has gathered all of the necessary diagnostic information, he/she will sit down with a patient to develop a treatment plan which will give the patient the best functional result.

## 6. Understanding Your Treatment Options

Depending on a patient's specific needs, possible treatments to restore functionality can include:

- Reconstructive neurosurgery
- Pain control management
- Physical and Occupational Therapy

For neurapraxic injuries, like stingers and other low impact nerve injuries, surgery is rarely needed. Treatment generally will consist of rest, physical therapy and pain management. Recovery is usually complete within approximately three to four months.

### *Reconstructive Neurosurgery*

For more significant injuries, a patient's treatment team will devise a reconstructive plan to restore as much useful function as possible to the affected arm. For severe brachial plexus injuries, prompt surgery typically provides the greatest opportunity for successful recovery. Without it, a patient might have a lasting disability and remain unable to use their arm or hand normally.

The primary ways in which we restore this function are:

- Nerve grafting
- Nerve transfer
- Tendon transfer
- Muscle transplant

Reconstructive surgery for complete brachial plexus injuries generally consists of a combination of nerve grafting and nerve transfer procedures. The treatment for each patient will be determined according to his or her specific injury pattern.

### *Nerve Grafting*

When a nerve is severely injured, the axons are divided. The severed axons that maintain their connection to the spinal cord will sprout regenerating nerve units. These will look for an appropriate nerve pathway to grow back down the distal nerve in order to find appropriate muscle or skin to connect to. But if there is an impediment to that regrowth, scarred nerve ($4^{th}$ degree injury) or disrupted nerve ($5^{th}$ degree injury), surgery is required to restore an effective pathway.

While the nerve ends can sometimes be sewn back together microsurgically, when the area is more extensive or over a length of nerve, a way to bridge that gap must be found. That is when a ***nerve graft*** is used. A nerve graft is a piece of "expendable" nerve from another part of the body which is transplanted to the damaged nerve site. This creates a bridge for the axons to grow through, replacing the damaged region , and enabling the axons to find their way back to their mending destination.

Nerve grafts are taken from many locations. The sural nerve is found in the back of the leg, extending from behind the knee to the ankle. This is a very long nerve that provides feeling solely to the side of the foot. This nerve makes an excellent bridge. Other nerves that we use are those which provide feeling on the forearm by the elbow, or even behind the ear. When these nerves are taken there is no loss of movement and only a small region of numbness results. Even this small area of numbness becomes less noticeable with time.

The damaged nerve is then cut away from the healthy nerve and, once we have found good healthy nerve on both sides of the damage, we then suture the nerve grafts between those two healthy ends. The axons can then grow from the stump closest to the spinal cord, through that graft, back into the healthy nerve on the other side of the damage, and on to the skin and muscle which had previously been lacking sensation and paralyzed.

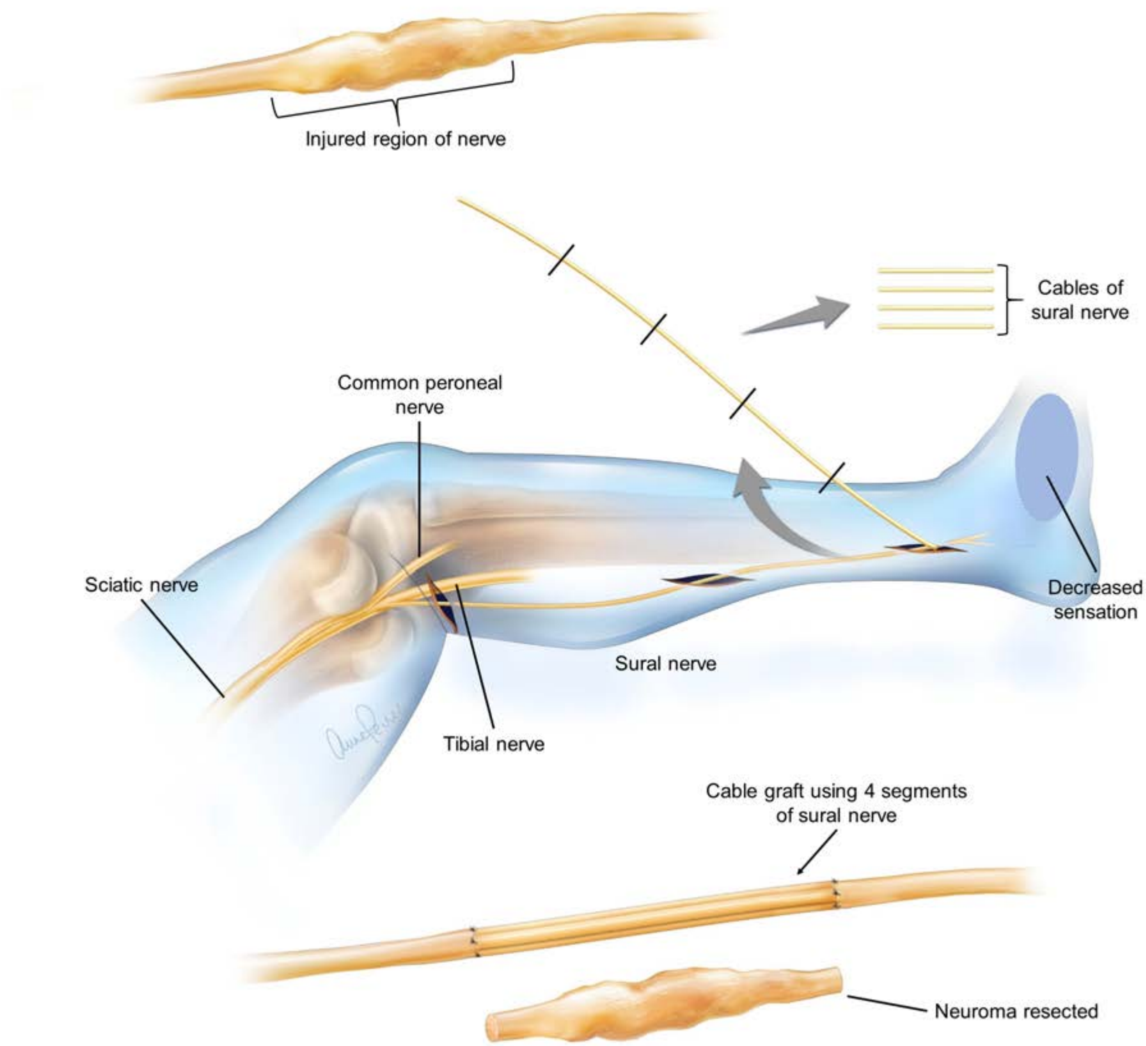



Fig. 6. Nerve graft: Using the sural nerve, a scarred segment of nerve can be removed and a graft placed to allow the axons a pathway past the area of injury to the distal nerve. Taking this nerve results in a region of numbness on the side of the foot. No weakness results.

### *Tendon Transfer*

The second modality (or intervention remedy) for a brachial plexus injury is a tendon transfer. Tendon transfers are also commonly used to restore movement in limbs. This procedure takes a working muscle and moves one end of it (the distal tendon) from its original attachment to a new attachment site to produce a more important movement.

To understand a tendon transfer, it's important to know a little about the relationship between muscles, tendons and nerves. Tendons attach our muscles to our bones. Every muscle has a starting point called the "origin". The muscle tapers down to a tendon, which attaches the muscle to a bone. Where the tendon attaches to the bone is called the "insertion". When the muscle receives a signal to move, it contracts and the muscle shortens, causing the joint to move.

Tendon transfer surgery involves taking a tendon from its original insertion and attaching it to another site. The starting point or origin of the muscle, the nerve supply and the blood supply are all left in place. Depending on the particular injury, the tendon may be attached to another bone or to another tendon to restore function to the injured area. Once this is completed, when this muscle contracts, it produces a new action depending on where the tendon is inserted.

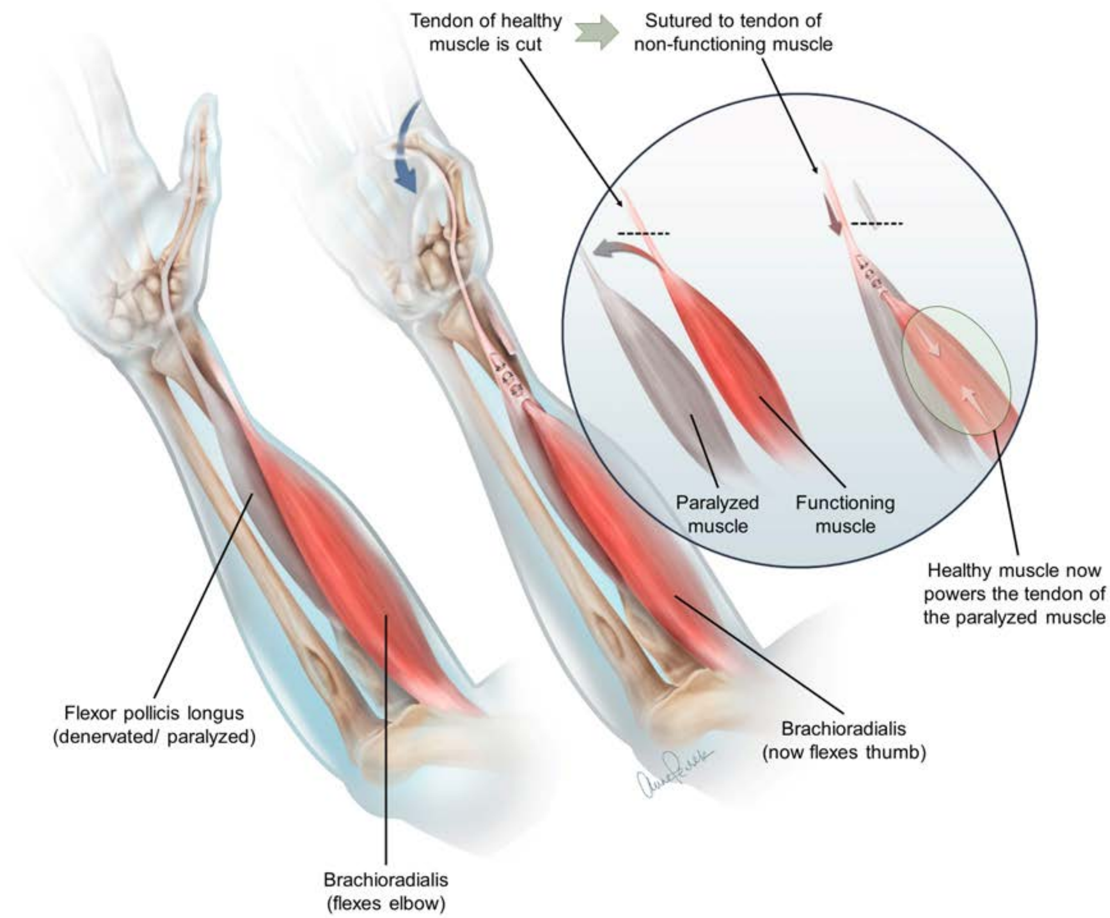



Figure 7. Tendon transfer: A muscle that is under good control is cut and sutured to the tendon of a non-functioning muscle. This allows the paralyzed movement to be restored by a new method.

After this procedure is performed there is typically a period of immobilization where the limb is placed in a splint to allow that tendon repair to heal and become more secure. The recovered movement is available almost immediately, but the limb must be treated with care for at least 6 weeks following the operation. Therapy is involved early to move the limb passively (without applying opposing force or resistance) and avoid scarring of the nerves. This procedure can be performed well after the nerve injury occurs as there is no prescribed procedure time limit.

### *Muscle Transplant*

Sometimes a local tendon transfer is simply not an available option. If the time window for nerve repair has passed and no tendon transfers are possible, there is, however, one option that typically remains. In these cases, a procedure known as a *free functional muscle transplant* (FFMT) can be used to embed a muscle into the limb to provide the missing function.

Muscle transplants are often selected over a nerve graft because too much time has transpired since the injury and a nerve repair would no longer be effective. Muscle transplants can be done at almost any time, even years after a patient's injury.

In a muscle transplant, a healthy muscle is harvested from another part of the body and transplanted into the affected area. The transplanted muscle tissue is then connected to the blood supply in its new location in order for it to survive in its new location. The transplanted muscle is also connected to a working nerve so that movement is possible. Similar to other nerve repairs, when that nerve is connected to the transplanted muscle's nerve, the axons must grow into that transplanted muscle before it will contract. Therefore, after surgery it typically takes about 6 months before the patient's transplanted muscle can move.

One of the most common muscles transferred for brachial plexus injuries is the gracilis muscle. This is a thin, long muscle of the inner thigh. This is the smallest of several muscles that bring the thighs together. It is employed because its loss is well-tolerated. This muscle is often transplanted into the arm to help restore the ability to bend the elbow and flex the fingers. In fact, people can run and participate in sports with this muscle missing without a problem.

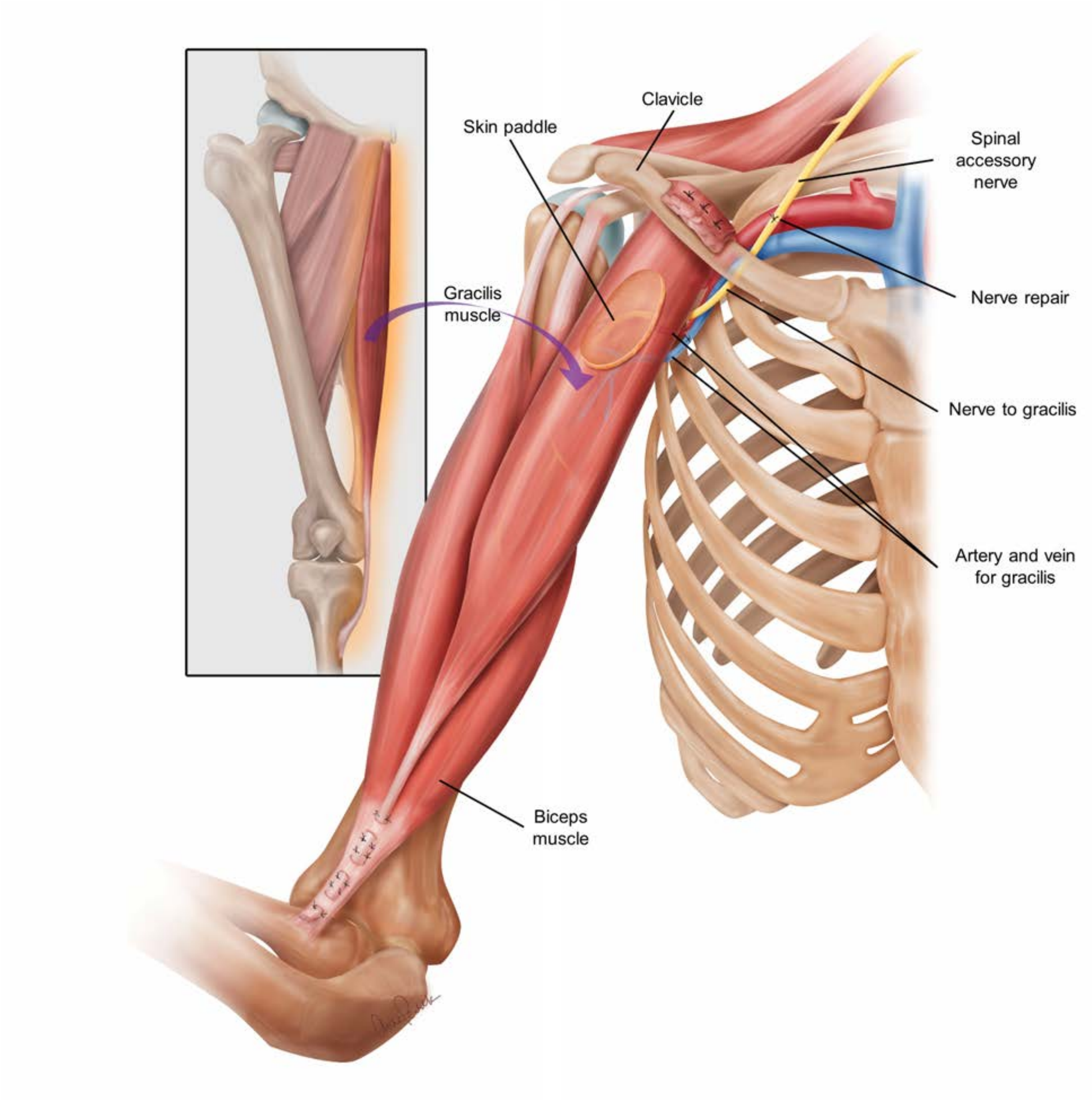



Figure. 8. Muscle transplant: A muscle that is not critical for leg function, the gracilis, is removed and placed into the arm to replace a missing function.  It must be connected to an artery and vein to survive in the new location.  It must also be connected to a nearby nerve in order to recover function.

Some of the advantages of a muscle transplants include:

- Restoration of function is possible even after a long period of time has transpired; and,
- Muscle transplants are time-tested procedures and we have decades of experience; and,

- Transplants represent an option to restore function when no other procedures are available.

Following this procedure, the patient must remain in the hospital for several days to ensure that the transplanted tissue’s new blood supply from the newly sutured vessels continues to flow well. Sometimes this includes a stay in the intensive care unit where a doppler machine is used to listen to the blood flow every hour.  Once the muscle “takes” it will still be some time before it begins to function.

### ***Nerve Transfer***

Nerve transfer is the MVP (most valuable player) of nerve reconstruction. Nerve transfers are one of the most commonly performed surgical procedures at the Paralysis Center.

Nerve transfers take healthy nerves with less important roles — or for which there are other muscles that perform the same function — and connect or “transfer” them to a more critical, but paralyzed nerve.  In other words, sometimes we have more nerves than we need to perform certain movements. When a nerve isn’t working, we can sometimes simply take a branch or a portion of a nerve from another location, reroute it, and connect it to a damaged nerve. This rerouting allows the nerve to send its axons or wires down to that distal nerve and restore movement to the corresponding muscle.

Motor nerves are transferred to re-innervate muscles; sensory nerves are transferred to restore sensation. Your surgeon will use functioning nerves that are close to the target muscle or sensory area in order to restore those functions as quickly and effectively as possible. These nerves are then transferred to the injured nerve that no longer functions. The nerve that has been transferred now takes over the function of the damaged nerve.

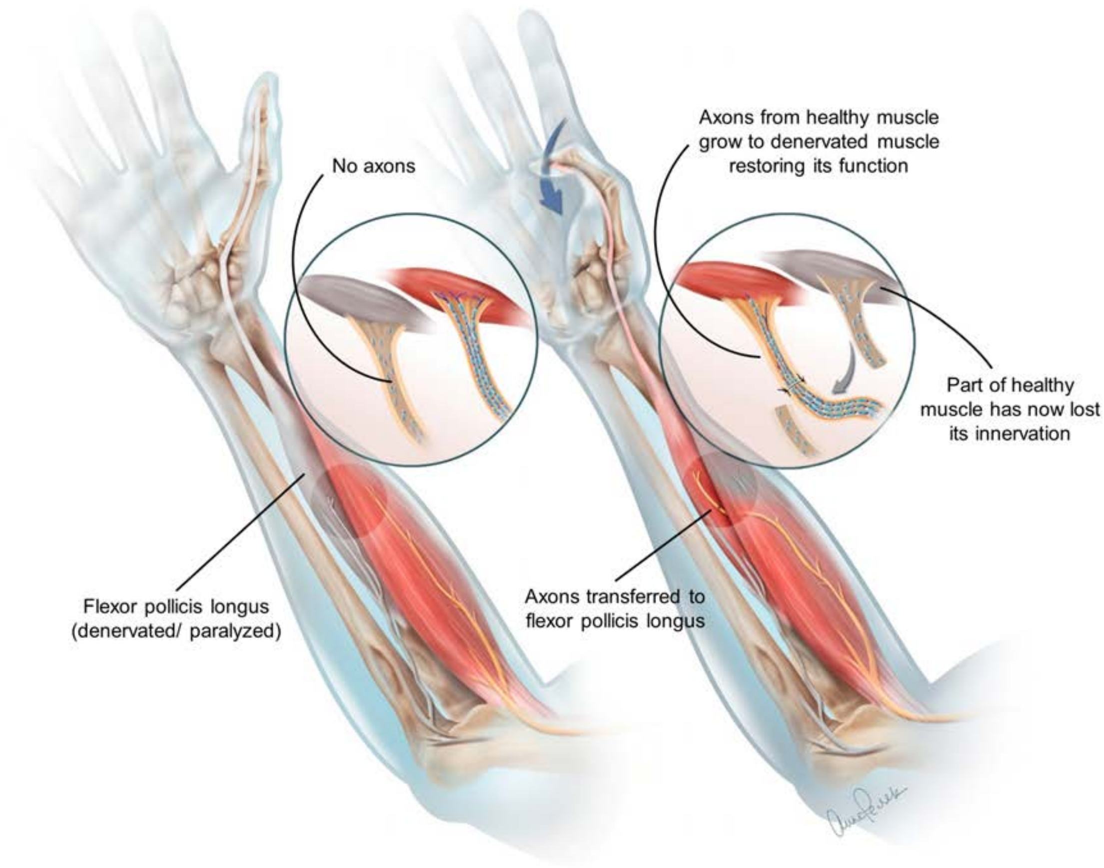



Figure 9. Nerve transfer: With a nerve transfer, axons of a healthy nerve are redirected from a less important target to a more important target, waking up the paralyzed muscle to accomplish its original function.

One of the most successful examples of nerve transfer is known as the “Oberlin” nerve transfer. Named after French orthopedic surgeon, Christophe Oberlin, this procedure is used to restore elbow flexion function by transferring nerve fascicles from the median or ulnar nerves to the biceps muscle nerve branch. As described earlier, when you cut a nerve, you can see several little nerves within it that make up that nerve trunk. You can tease (pull) them apart gently and peel out one of those sub-nerves. We then cut that portion of the nerve and directly suture that to the nerve branch that runs to the biceps muscle. The result is effective elbow flexion that comes rapidly after the operation, sometimes as quickly as within 3-4 months.

In an upper plexus injury, as discussed previously, we are typically missing elbow flexion and shoulder function. Shoulder function is primarily driven by the deltoid (muscle) and, most importantly, the two muscles that sit on the scapula – the supraspinatus and infraspinatus. These last 2 muscles are innervated by the suprascapular nerve. An important nerve transfer that we use in these cases is the spinal accessory nerve which provides shoulder shrugging. That nerve can be cut and its lower portion transferred to the suprascapular nerve. That nerve innervates the supraspinatus and the infraspinatus muscles. The supraspinatus causes the arm to move out to the side. The infraspinatus causes it to rotate away from your body. So we can connect that spinal accessory nerve to the suprascapular nerve to get those critical shoulder functions going.

These are just two examples of the many ways healthy nerves can be transferred to restore function after nerves have been damaged.

One of the main advantages of a nerve transfer is the potential for faster reconnection and restoration of function. Other advantages in choosing a nerve transfer include:

- Restoration of the original muscle’s function without changing the arm's anatomy; and,
- No or limited casting and immobilization; and,
- Sacrificing one simple function can potentially restore multiple functions.

Advances in nerve transfer procedures have furthered the treatment of paralyzing injuries to a whole new level of success.

## *7.* Why Nerve Transfers are so Successful in Reversing Many Forms of Paralysis

Of all the types of reconstructive procedures that a neurosurgeon can offer a patient with a paralyzing injury, the nerve transfer procedure is the one that has afforded the practice of nerve repair to a whole new degree of achievement.  Patients who once had little hope of regaining functional use of their extremities are now able to have movement restored in ways not previously believed possible.

### *Nerve Transfer as MVP (Most Valuable Player)*

Today, so much more is possible. We now have the ability to see even the tiniest nerve fibers and blood vessels. We are able to explore the anatomy of an injury through non-invasive types of imagery such as MRI's, CT scans and other diagnostic tools. We know so much more about how nerves work in the body, how they heal and how they grow.

With the success of nerve transfers with brachial plexus injuries, researchers and neurosurgeons have started to consider utilizing this procedure with other paralyzing injuries as well. Using similar techniques, nerve transfer specialists are having great success in restoring motor function and sensation for a variety of paralyzing conditions, including spinal cord injuries, stroke and other nerve injuries.

Nerve transfers, more than any other of the reconstructive procedures, have yielded results which  are making a substantial difference in the lives of our patients. Nerve transfers result in quicker recovery and more reliable results. Of course, the degree of restored function is unique to the individual, but these outcomes mean that more people with different types of paralysis have the potential to be helped in ways impossible in the past .

## 8. Post Operative Rehabilitation

***Physical and Occupational Therapy***

Successful nerve reconstruction doesn't end with the recommended surgery. Following surgery, it is imperative that a patient begins rehabilitation to mobilize and strengthen the affected area. It is important that a patient seeks an OT (occupational therapist) or PT (physical therapist) who is competent and comfortable in this important step. A nerve transfer is like planting a garden. The "wires" inside the nerve need time to take root and grow down to the muscle they're going to re-innervate. That takes time – from a few months, to as long as two years. Rehabilitation, using physical and occupational therapies, will help to maintain passive range of motion, recognize and activate new muscle movements, and accelerate strengthening. Once some strength is achieved, therapy is helpful in learning how to incorporate those new movements into daily activities.

How much recovery can be expected? This depends on many factors. The chances of success are best if we operate earlier, if we make a connection closer to the target muscle, and if we can use a source with a large number of axons. It also makes a big difference if the patient doesn't use any nicotine products, as regeneration requires the development of microvessels to supply nutrients to those growing neurites. The use of marijuana products could also impact the ability to focus on the rigorous and regular exercise regimen required post operatively for strengthening donor muscles to activate the recovered motions.

Once a patient has had a nerve transfer, their muscles and nerves have to "learn" to coordinate new movements. For example, surgeons routinely use donor nerves from the chest area when repairing a nerve injury in the arm. In the case of a nerve transfer that uses an intercostal nerve (donor) to restore movement in your arm, intercostal nerves assist the diaphragm with breathing and chest wall movement. When a nerve is transferred, it takes time to learn new movement patterns. So, in this example, you might have to initially take a breath (activating the transferred nerve) to move your arm. Over time and with training, the brain learns the new pattern and you'll be able to move your arm just by intending to do so. Establishing that pattern takes time, and rehabilitation lays the foundation for that learning.

Typically once the surgeon has cleared the patient to begin the rehabilitative process, the patient will need to follow up with the surgeon and lead therapist every 3 months up to 3 years, depending on the complexity of the reconstruction.

## 9. But What About…?

You've probably done a lot of research on brachial plexus injuries and the treatment options. You've likely seen mention of some other treatment modalities (methods) and approaches. Let's talk a little about two of the most commonly mentioned possibilities.

### *Stem Cell Therapy*

Stem cell therapy has become quite popular for treating a number of conditions. Only a very few types of stem cell treatments are currently approved by the FDA. Some of these interventions that have shown promise include:

- Hematopoietic (or blood) stem cell transplantation
- Skin stem cells have been used to grow skin grafts for patients with severe burns
- Stem cell therapy for corneal regeneration
- Mesenchymal stem cells for bone and cartilage damage

You may be thinking, "If they can repair skin and bone, why can't they heal nerves?" The short answer is, "We're trying."

Researchers at some of the major medical research centers are exploring the possibility of using stem cells to stimulate neuroregeneration and axogenesis. Just a few of the many clinical research projects related to stem cells and nerve regeneration include:

- Immune response and neuroregeneration
- Spinal cord repair
- Peripheral nerve regeneration and repair
- Nerve cell regrowth: Axogenesis
- Stroke neuroregeneration

These sound exciting, right? Stem cells are one path of hope for many diseases and conditions. But what do the outcomes tell us so far?

There have been a good number of clinical trials and research projects that have been undertaken using stem cells to treat spinal cord injury and brain injury. However, at this point, there has been no significant degree of clinical success for patients. Unfortunately, there are many instances of patients travelling abroad and paying tens of thousands of dollars (sometimes hundreds of thousands) for stem cell treatments from clinics who claim they can reverse paralysis, with results ranging from disappointing to catastrophic.

But it's not all bad news. There have been successes in animal models with rats and mice, discoveries that we hope will be translated successfully into human trials in the near future. What makes stem cells even more complicated is that the nerve regeneration problem remains.

One of the applications that our labs are looking into currently is using stem cells to preserve the nerve and muscle so that the "window of opportunity" to recover a muscle might be extended, allowing nerve reconstruction years after injury . . . but we have a lot more work to do!

Exciting results are emerging with stem cell research in our animal models. We collaborate with other labs within the Harvard system on a regular basis, trying to translate their basic science ideas into clinical applications. In other words, we do a lot of collaborative studies where we bring the ideas that would apply in the clinic with the animal models and consider different ways to apply these stem cells.

We're hopeful that sometime in the future these studies will lead to new procedures for patients to restore more function, but more research is required to reach our ultimate goals.

### *Robotic Arm*

While stem cell therapies are probably still somewhere in the future, there are some exciting options coming down the line with robotic arms. When you hear that, you may have visions of Ironman. The idea is similar but these are not Tony Stark's arms. Today's robotic arms are the product of the meeting of research, clinical application and technology, all combined to create a positive patient outcome.

The limbs being developed are very sophisticated. They require very little input to deliver a pretty hefty level of function to the arm and hand. If we have just a couple of muscles that we have control over in that arm, their electrical triggers can create a sophisticated hand opening and hand closing, elbow flexing and much more than you might expect with just a few subtle pulses of energy.

Unfortunately, these robotic arms are not presently commercially available. They largely remain in clinical trials and experimental programs (and are still quite heavy). We hope that they will be readily available to patients within the next 10 years. These functional limb replacements have the potential to significantly change the lives of patients who have suffered complete neural injuries, and for whom nerve reconstruction may not have been successful.

Until these future solutions are available, the best option remains reconstructive neurosurgical approaches for patients with significant paralyzing injuries.

## 10. Brachial Plexus Patient Stories

We've talked a lot about brachial plexus injuries and the various ways that we can restore functionality to damaged nerves.

We've talked about the importance of getting an accurate diagnosis. And, we've talked about all the reasons why a multidisciplinary treatment approach will give you the very best treatment plan and chance for success post-operatively. Now it's time to meet some of our patients and hear about their journey in their own words.

### Kyle's Story

Brachial Plexus injury, multiple surgeries: nerve transfers

*"Find a specialist, someone who specializes in this kind of injury, the Brachial Plexus injury . . . because a typical neurologist at a hospital won't give you the right diagnosis. They don't have the tools to do so."*

*"About three years ago now, I was out in Thailand. I loved Thailand and the accident happened, literally, on the very last day of our trip. I was with friends and we decided to rent scooters that day. So I was riding a little motor scooter in kind of a hilly environment and as I was taking a turn on the road, a bus came pretty much speeding head on into my lane and hit me head on. It threw me across the pavement and banged up my body a bit. I was in a coma for a week to two weeks after the accident and then flown back to the United States.*

*I was taken into a trauma care unit here in San Diego and they put me in a neck brace and did all the things that a trauma unit does, like MRI's, things of that nature. I had jaw surgery there on the spot. My jaw had been shattered in two places and I had a brace put in and that was something they told me afterwards – I was pretty out of it at that time. I didn't have brain damage, but I was still kind of waking up and figuring out what the heck was going on with my life.*

*My left arm wasn't working at all, and in my head, I'd been thinking, "I'm sure it's just something temporary that's going to heal– it's part of the accident. I'll be fine."*

*The doctors at the trauma care unit were saying, "Yeah. It's going take a little while to heal. Just give it time and you'll get better." I said, "All right." And so the next couple months I was pretty much couch-locked. I was just sitting there recovering. I had a lot of spare time and I started doing research.*

*I read some articles and the medical journals on my injury, and what I kept noticing in the articles was that they kept saying to find a specialist, someone who specializes in this kind of injury, the brachial plexus injury, and find them because a typical neurologist at a hospital won't give you the right diagnosis. They don't have the tools to do so.*

*So I began to look around and see if there was anyone in my local area that specializes in this type of injury, and that's where I came across Dr. Brown. When we got in contact with him and his office, they took me in pretty quickly. The first thing he did, he set me up with some pretty high-powered MRI's to really get a good look at things. And it was a couple of weeks after that when we got back together. He looked at me and said: "All right, you're going to need to be operated on to have any sort of real improvement. It's not going to get better on its own. They were incorrect with their diagnosis and I need to operate."*

*And so I agreed to this. I wanted to get better and so over the next couple of months, we did various tests. I think it's an EEG. It's something where they put a bunch of needles into me and had me try and move my arm in various ways to see which muscles and nerves were firing and which weren't.*

*After a couple of months Dr Brown did the first surgery. The first surgery went well and I recovered from that, and then he said: "All right, let's do another one." He did another surgery then. And then we waited for 5 - 6 months and I actually started the recovery, little bits of it at a time. My left bicep started to twitch and move and I was actually starting to see some improvement.*

*What Dr. Brown had been telling me was that he was hoping for a little more recovery and he wanted to wait and see but there may be a need for a third surgery. So we waited and waited and eventually got to a point where he said: "All right, we hadn't had as much recovery as we wanted from the second surgery, so we're going to do a third surgery."*

*And this was a bigger one. They went into my ribcage. I have a big scar on my side now, but that was my third and final surgery and that took a little bit longer in terms of recovery but I think it was good and I'd say now for the most part, we've had success. The very first one had two parts to it. One of the parts was a success. One of them not so much, but everything else has been good and I now have a pretty functional arm by comparison with where I once was. I can carry things. I can close doors. I can get a lot of use out of it.*

*It still has an issue but it's certainly much, much better than where I was prior to seeing Dr. Brown.*

*The nerve transfer surgeries are all total successes. I think the proper term is neurotization. Everything he did with those, I've shown recovery. I have actually a pretty strong bicep. I can lift a good amount of weight with it.*

*The only surgery that did not work out was where he did a nerve graft from my neck into my shoulder. But everything else beside that, all the nerve transfers, they all worked amazingly.*

*For a while there, I'd do lifting weights and doing physical therapy exercises and I was noticeably seeing strength improvements and better functionality.*

*The biggest thing I'd stress would be finding someone capable, someone who understands the issue and can either guide you to someone who can fix it or who can fix it themselves. Dr. Brown is one of those many surgeons. I feel like I owe Dr. Brown, as the work he has done for me is incredible. He even referred me if I needed to see someone as he's not in San Diego anymore. He gave me some people that I could reach out to.*

*And so there are people out there that can help. It just takes some work on a patient's part to seek that. And I would really stress to do that, because it's time-sensitive. If I hadn't gone and found him in the time soon after I had these injuries, there's kind of a shut off window. So it needs to be done sooner rather than later.*

*And Thailand – I loved it and I would still go back. I had a lot of fun there. But I would not get back on a motor scooter."*

***Dr. Brown's Comments***

Kyle had a very severe injury of his brachial plexus and was smart to do his homework and get to a center that treats these injuries in a timely fashion. His injury was extensive and involved avulsions, ruptures and stretch injuries leaving him with weak hand function and little else. Imaging helped us determine which roots were avulsed and thus would never recover and EMG helped us determine whether the weakened nerves were still strong enough to be used for nerve transfers to recovery the critical functions.

Kyle's reconstruction required a staged complex approach, utilizing nerve transfers and nerve grafting. The nerve grafting took place in the neck and the nerve transfers took place in the neck, in the arm and in the chest. Complex injuries like Kyle's require complex reconstructions. By fully understanding the extent of the injury and available nerves we were able to devise a plan that would restore his shoulder, chest and arm giving him functional use of that limb once again. Without timely intervention he would not have been able to recovery nearly as much function. It is worth noting that while his arm now functions usefully, it is not a normal arm and not nearly as strong as the other arm. This is a realistic outcome when injuries are severe and we always want patients to have realistic expectations.

## A Mother's Story - Diana

Josh – snowboard accident Brachial Plexus injury – nerve transfer surgeries

*"Dr. Brown saved my son's arm. I couldn't get anybody else to see Josh within that three-month window and Dr. Brown did. And not only did he see him, but he did surgery on him at six weeks, post injury. That's why my son has his arm back."*

*"It was December 28, 2016. My son, Josh, was 17 at that time, a very, very active 17-year-old. He was a senior in high school. We lived in Orange County, California, and he was a competitive surfer. He was on our high school surf team poised to take CIF, having the best year ever. He also played soccer. In addition to those sports, in his free time, he liked to wake board, skate board and snow board. He's into those kind of more extreme sports.*

*On 28 December he went up to Bear Mountain with some buddies as he had done for a year or two. He's grown up snowboarding, and he's very good, very familiar with the mountain, very familiar with the run he was on, and very familiar with the jump that he went off. He is very skilled, and was not doing anything outside of his ability or comfort zone. On this day he just hit the jump, wasn't able to land and essentially fell out of the sky. He came down on the right side of his body, crushing it. He broke five ribs. The clavicle was shattered and part of that punctured his lung as well as compressed the brachial plexus and subclavian artery.*

*And then his arm – Josh said he felt it go numb, his right arm from his shoulder to his finger tips. As a result of the injuries, he was airlifted to the local mountain hospital at which time they determined he had no flow of blood to his right arm. And so he was airlifted to a trauma center nearby where my husband and I met him. It was devastating for us as parents.*

*He received treatment there and the good news was that he did actually have blood flow through his arm. It was definitely limited but it was enough to sustain the viability of his arm. It was then decided that he was to have surgery on the clavicle. They needed to repair the broken collar bone and get the compression off of the artery and the network of nerves. But he wasn't in an emergency life and death situation anymore, so he didn't have that surgery until the following morning at which time they put a plate on his collar bone. The puncture to the lung was minor. They didn't have to do a patch. So he was medically in good shape, except for the right arm. He was put in the kids' ICU because he was only 17. The right arm was paralyzed because the brachial plexus was compressed for too long and just wasn't viable anymore.*

*At that time they didn't know if he had an avulsion or if he had a rupture. They recommended we see a neurologist who specializes in brachial plexus injuries to determine the full extent of his injuries.*

*I took him to an orthopedic here in Orange County. I know that they're not neurologists but I didn't know what else to do. They specialize in these types of sports' injuries and doing EMT's. Via the EMT, we learned that there was no life in his nerves. So I started researching and came to find the Mayo Clinic in Rochester, Minnesota. I connected with Mayo Clinic and I found Dr. Brown.*

*I was able to get a first appointment with Dr. Brown on 23 January, 3 weeks after the injury.*

*In the meantime, I'd had MRI’s done. We also had CT scans done to try to determine what the extent of damage was to the brachial plexus. And everything came back with no avulsions, no ruptures, no tears, so results were somewhat inconclusive.*

*At the appointment with Doctor Brown he was kind of looking at me with the expression: “This is bizarre. I've never really had a situation like this where we can't determine why his arm is paralyzed because the scans and the MRIs don't show any avulsions, ruptures or tears.”*

*So he said, “I can’t see behind that plate. A plate is about seven inches long with seven screws. And we can’t see behind that. And so, I don’t know if there’s something going on behind that plate, without doing exploratory surgery.” He was somewhat hesitant and was of the mind to maybe wait, but there were risks in waiting. After exploring the options, Dr Brown, my son Josh, and I, opted for that exploratory surgery.*

*The surgery took place at 6 weeks. The good news … there weren’t avulsions, ruptures, and tears. It was just massive scar tissue. And Dr. Brown spent six or seven hours removing the scar tissue. The long thoracic nerve had such extensive scar tissue that he felt in getting it all removed, the nerve might be damaged. So he did a nerve graft from my son’s leg. The surgery was successful and slowly but surely, he started to recover. And as soon as he could he started physical therapy and we followed the regime and the protocol.*

*Over time his arm started to ‘come back.’ And then his hand started to ‘come back’ a little. I did actually end up taking him to Boston. He’s seen Dr. Brown in Boston twice and I took him to the Mayo Clinic too just to get a confirming opinion.*

*His hand wasn’t improving as quickly. Nerves grow very slowly but the unfortunate part of nerve damage, is your muscles can atrophy to the point of not being recoverable and your small intrinsic and extrinsic muscles in your hand can’t be transplanted. So if those muscles die off before the nerves make it to them that’s a serious loss.*

*I wanted to make sure we were doing everything we could medically, to ‘get that hand back.’ The good news is that the Mayo Clinic and Dr. Brown had identical recommendations. We learned that further surgery could be done taking a tendon from one of the fingers and attaching it to the thumb, but that decision could be made at a later stage when we see how much of the hand ‘came back.’*

*We are coming up to three years this December. And although he has used enough of his hand to function daily, his hand is not one hundred percent. His fingers don’t fully extend or straighten flat, on a flat surface. His have a little bit of an arc to them via that middle knuckle. But he has learned to compensate and the hand’s ‘come back’ enough that if someone didn’t know he had had this accident, they would never know.*

*He’s back surfing. We let him go to college. He had applied and was accepted back in his senior year to go to the University of Hawaii, for surfing first and education second. And he’s doing amazingly well. We were really hesitant to let him go, but we did. And it was the right decision. He’s on track to graduate in four years. He’s actually doing double major there. He couldn’t be doing better. That kid is living his best life. We couldn’t be more proud.*

*I would have done anything to give him his arm back. He’s got his arm. Exterior rotation isn’t quite as strong as or as vast, but it’s still getting better and better. I would say his arm is 95-99%. As far as I’m concerned, it’s a hundred percent, because he is doing everything he wants* *to do.  He is surfing fully, twice a day, every day, and that is therapy for Josh. Just in the paddling part of surfing, that's good exterior rotation. And he has to take that right hand and he has to push that down on the board as he stands up. And he didn't have enough strength in the beginning to do that. And now that's no problem at all. He's not impaired.*

*And the one thing I'll tell you if you were to say to me, why do you think your son recovered and another patient has not?*

*My answer will be two things. It would be Dr. Brown. He's amazing. I mean he's just amazing. He saved my son's arm. I couldn't get anybody else to see Josh within that three-month window and Dr Brown did. And not only did he see him, but he did surgery on him at six weeks post injury. That's why my son has his arm back. I'm absolutely 100 percent convinced. In fact, Mayo Clinic actually even said that. When I took him there, they said: "Your son is a prime example of why early intervention is key, and we need to rethink why we don't see patients until the three-month mark."*

*So Dr. Brown is the reason that his arm is back, through his amazing skills and early intervention.  He has a stellar reputation. He saved my kid's arm. I know that's not as profound or as monumental as someone saying this doctor saved my kid's life, but he saved my kid's life the way he knows it or the way he knew it, and now knows it again*.

*My son's attitude is the other factor. He never had a thought that, "I'm not going to recover." His attitude was: "The injury happened and now I need to focus on getting better. " He had such a positive attitude and belief.  You have no idea.*

*Finally, I would say, early intervention is key, no matter what the cause, no matter how bad the injury. Do your research so that you are informed.  Publications and the internet are powerful resources.  And if you have the means to travel to the leading professionals in that specialized field, then do that."*

***Dr. Brown's Comments***

*Joshua had a very unusual injury.  Unlike Kyle, there were no avulsions and no ruptures.  Most of the nerves were available and recoverable, but crushed under scar tissue from his injury. Early surgery was critical in this case and resulted in one of the best outcomes I have seen in a patient that presented with a completely paralyzed arm.  We were able to watch the progression of nerve regeneration over time starting a few weeks after the surgery and marching down to the hand over the next 3 years.  Eventually this reached the small muscles of the hand, a target that most surgeons will tell you is impossible to recover. It is not impossible, but it is uncommon. Early surgery makes this much more likely.*

## 11. Are You a Candidate for Nerve Reconstruction?

Now that you've learned more about brachial plexus injuries and the various procedures that can restore functionality, you may be wondering whether nerve reconstruction is right for you.

As a reconstructive neurosurgeon, I believe that anyone with a debilitating nerve injury is a potential candidate for reconstructive surgery. Even for those for whom nerve reconstruction isn't an option, there is usually something we can do to help alleviate discomfort and restore some level of functional use of the injured limb.

There are a few types of patients that require special consideration: the elderly; those who are not committed to the hard work required of post-surgery rehabilitation, and those with debilitating chronic pain.

- With the elderly, special consideration has to be given to their health status and the risk of undergoing major surgery. As we age, our ability to tolerate surgical trauma, anesthesia and the demands of recovery can pose a danger. Age doesn't disqualify someone from a nerve reconstruction procedure, but it does require special consideration and evaluation.
- When people learn that nerve construction can potentially reverse their paralysis and restore their functioning, they are willing to agree to almost anything to get their surgery. However, what they're sometimes less willing to agree to, is the long, hard road to recovery. Recovery means hours of physical therapy which is not always pleasant. Recovery requires home exercise. Recovery requires on-going follow up appointments for as long as three years, sometimes longer. Not surprisingly, people who cannot commit to the post-surgical requirements may have less than optimal outcomes. Compliance and challenging, long-term therapeutic discipline matters.
- Finally, people who have ongoing, debilitating chronic pain may have difficulty with the post-operative rehabilitation program because of their pain levels. Having chronic pain doesn't exclude someone from surgery. It is a factor to consider in the patient's overall plan of care. Rehabilitation is critically important to the restoration of movement and strength. There are relatively few patients I wouldn't recommend for a procedure, because if they give up now, there are no future options. If later on the pain is better controlled, patients can at least recover their muscle functions and learn to use their muscles as their healing process progresses.

None of these situations automatically exclude a patient from consideration for treatment. Each patient is evaluated independently and decisions are made based on their clinical presentation and the best treatment options for their specific injury.

Ideally, we want to see patients within three months of their injury. The sooner that they are seen, the greater the number of possible options for reconstruction. If it's been longer than three months but less than a year, there are still options that can be considered.

But even if it's been a year or many years after, don't despair. The fact is, there is always something that potentially can be done. ***There are options and there is always hope!***

## 12. Tips To Help You Prepare For Your Appointment

We know that seeing a new specialist can be stressful. We want you to be fully informed and be an active participant in your care. You will be sharing a lot of information at that first visit. You'll be asked a lot of questions. You may be sent for tests. It's a lot to take in.

Here are some tips we give to our new patients to help them prepare for that first appointment:

- Bring along a family member or friend. You'll be receiving a lot of information. It's hard to remember everything. Having someone along will help you remember key information.
- Write down the details of your injury. Knowing when it happened and the circumstances is important information for your doctor.
- If you have copies of pertinent records, bring them. If you don't, that's ok. We can request what is needed from past physicians.
- Bring a CD with your MRIs, CT scans and x-rays.  These images are critical and a paper report is not enough for the doctors to review.
- Make a list of your past treatment for your injury. Knowing what treatment have occurred is important for your doctor to know.
- Bring a list of all medications you may be taking. Don't forget to include any supplements or over-the-counter meds you may take.
- Don't be afraid to ask questions. Make a list of any/all questions that you have.
- If tests are ordered, be sure to ask about any special preparation or precautions you need to be aware of for the test(s).

Once your diagnostic evaluation and testing are complete, you and your specialist can discuss treatment options and recommendations that can give you the best chance of restoring function to your injured nerves and muscles.

Coming for a consult or evaluation doesn't necessarily mean surgery is imminent. As healthcare providers, our role is to give you our best recommendations and provide you with the best care possible. Once your evaluation is complete, the steps you take next are up to you. We understand that you may not be ready for a surgery yet. It's ok if you need to take some time to think it through. There is a lot to take in and we want you to make the best decision for you - a decision you are **totally** comfortable with.

***We are here when you are ready.***

## 13. Conclusion

*It is my hope that you've found this Guide informative and you now have a more thorough understanding of your injury and the best treatment options available.*

*Science and technology have given us tools that were unavailable even just a few years ago. We now have a number of surgical procedures available to treat injuries once dismissed as untreatable. Whether it's complete nerve reconstruction, nerve transfers, tendon transfers, muscle transplants,* ***there is always something we can do to help.***

*I hope that you found our patient stories inspiring. Kyle and Diana/Josh have shared their actual experiences with some of the very treatments you may be considering. It has been my privilege to treat them and I thank them for their honesty.*

*We have now reached the end of our journey together in this Guide, but I hope not forever.*

*If you have a specific question about something I didn't cover, then I welcome you to contact me via our website www.paralysiscenter.org.* ***If there is one takeaway from this patient guide, it's that you need to see a brachial plexus specialist as quickly as possible. Don't wait to see whether function returns.***

*If you would like to schedule an initial consult with me at the Paralysis Center in Boston, MA, we are accepting new patients. Mass General accepts just about all forms of medical insurance and also offers a financial assistance program. Additionally, if you are an international or out-of-town patient, Mass General provides you with support to book your travel and accommodation. Please visit www.massgeneral.org for more information.*

*For more information about treating brachial plexus injuries, including medical papers I have written and recordings of medical conferences I have taught at – please visit the Paralysis Center Education Center on our website: Paralysis.MGH.Harvard.edu*

*I encourage you to never give up hope, to always ask the hard questions, and, see a paralysis specialist as soon as possible.*

*I wish you good health and good luck as you continue on your journey.*

Justin M. Brown M.D.
*Director & Founder,*
The Paralysis Center

## 14. About Justin M. Brown M.D.

Justin M. Brown, MD is a board-certified neurosurgeon and global pioneer in Reconstructive Neurosurgery – an emerging specialty focusing upon surgical interventions to reverse the effects of paralyzing conditions. Dr. Brown believes that patients suffering from conditions of paralysis have had limited access to the treatments that would improve their condition because most centers across the world focus on only a single type of paralyzing condition, if any at all. Specialists in brachial plexus injury did not routinely see patients with spinal cord injury. Specialists in spinal cord injury hand reanimation often did not have expertise in spasticity. Developing expertise across all of these disorders provided benefit for each of these individual conditions and opened up options for conditions not previously considered for surgical restoration. Bringing all of the treatments for each of these conditions together into a single center has now allowed for all comers to receive the best in paralysis reversal care. Dr. Brown has received widespread, international recognition for this work. He is an avid educator and a regular featured speaker at medical symposiums around the world.

Dr. Brown's own training has been multidisciplinary in nature. He earned his medical degree from the Eastern Virginia Medical School in Norfolk, Virginia and completed an internship in General Surgery and residency in Neurosurgery at Baylor College of Medicine in Houston, Texas. Thereafter, based on his desire to understand paralysis problems from the perspective of another surgical specialty, Dr. Brown completed a peripheral nerve surgery fellowship in the Division of Plastic and Reconstructive Surgery at Washington University School of Medicine in St. Louis, Missouri. Then, in collaboration with a notable pioneer in Restorative Neurology, Milan R. Dimitrijevic, MD, PhD, he helped establish the International Society for Restorative Neurology. Dr. Brown is also a member of the American Society for Peripheral Nerve, The American Association for Hand Surgery, the AANS/CNS Section on Disorders of the Spine and Peripheral Nerves, the Congress of Neurological Surgeons, the American Association of Neurological Surgeons, the Pan-African Association of Christian Surgeons..

Dr. Justin Brown currently serves as Director of Reconstructive Neurosurgery at Massachusetts General Hospital, is Associate Professor of Neurosurgery at Harvard Medical School, and is the Founder and Director of the Paralysis Center.

## 15. The Paralysis Center At Massachusetts General Hospital

Founded in 2017 in conjunction with Spaulding Rehabilitation Hospital, the Paralysis Center is a world-class patient treatment and medical research center for all conditions resulting in weakness and paralysis

Using a team approach, the Paralysis Center unites a multi-disciplinary team “under one roof” who are leaders in their respective fields: Neurosurgery, Neurology, Physical Medicine and Rehabilitation, Physical and Occupational Therapy, Orthopedics and Plastic Surgery. We employ the best imaging and neurophysiology techniques available to give us the best information to inform our treatment plan.

At the same time, our research endeavors to both augment our current practice, as we collect detailed diagnostic, intervention and outcomes data for each patient, and, pave the way for new interventions that we hope to implement in coming years, which will further enhance the lives of our patients. Basic science endeavors are exploring methods, such as stem cell treatments, that will enhance our ability to apply even more effective treatment strategies in the future.

Such comprehensive care gives patients access to the most cutting-edge technology and proven paralysis-reversal treatments — providing a best-in-class treatment facility for every aspect of patient recovery.

No matter what form of paralysis you or a loved-one suffers from, or what medical advice you may have received before – there is hope. We *can* help you get movement back.

Schedule a consult with Dr. Brown today to better understand your treatment options by calling (844) 930-1001.

For more information, please visit: paralysis.mgh.harvard.edu