



**PENN**

**Neuro-Orthopaedic Service**



*Improving  
Mobility &  
Function*

*Restoring  
Dignity &  
Independence*

*A Patient Guide to  
Neuro - Orthopaedic Care*

# Introduction

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## What is Neuro-Orthopaedics?

**N**euro-Orthopaedics is a subspecialty of orthopaedic surgery that treats the musculoskeletal (muscle, tendon, bone and joint) consequences of neurologic disease. Neurologic disorders that commonly cause orthopaedic problems include stroke, brain injury, spinal cord injury, cerebral palsy, multiple sclerosis, polio, and Charcot-Marie-Tooth disease. Many orthopaedic problems occur as a complication of nervous system disorders and injuries. These orthopaedic problems include muscle spasticity, weakness, contractures and heterotopic bone.

Neuro-Orthopaedics is an approach to patient care that focuses on recovering lost function. The goal is to improve performance in a person with a permanent disability or chronic disease. This leads to improvement in the quality of life for the patient and their caretakers. Neuro-Orthopaedics views the functional problems of a patient in relation to the entire musculoskeletal system and not by a limb or joint.

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### The Penn Neuro-Orthopaedics Program

#### Improving mobility Restoring dignity and independence

**S**evere loss of movement is often the result of neurological disorders. This loss of movement can make even the most ordinary of daily activities impossible to accomplish. People affected by spasticity, contracture and loss of mobility may not be able to walk and may live without being able to wash, dress or feed themselves. Often confined to bed or to a wheelchair, these people need extensive care from family members and

their caregivers. Thousands of Americans cope with mobility disorders every day they are unable to walk, or perhaps they cannot feed, dress or wash themselves. Such mobility disorders are often the disabling aftermath of stroke, brain injury or other conditions. For these people and their families and caregivers, the Penn Neuro-Orthopaedics Program offers hope.



Michael suffered a brain injury in an automobile accident. He developed spasticity, contractures and heterotopic bone. After Neuro-Orthopaedic treatment he regained the ability to walk, work and enjoy life

At Penn, specialists work together to bring the latest advances in diagnosis and treatment to patients whose arms and legs are impaired by brain injury, stroke, anoxia, central nervous system disorders or orthopaedic conditions. We help people in the USA and around the world regain mobility, improving their lives.

Our program director, Dr. Mary Ann Keenan, is a pioneer in neuro-orthopaedics. She is one of the few orthopaedic surgeons trained and experienced in reconstructive neuro-orthopaedics. She has published and lectured extensively worldwide. Dr. Keenan has developed many of the evaluation and surgical techniques and is considered to be the foremost authority in neuro-orthopaedics.

Penn Neuro-Orthopaedics successfully treats a wide range of arm and leg problems, including:

- Stiff shoulder
- Flexed elbow deformity
- Clenched-fist and thumb-in-palm deformity
- Hip and knee contractures
- Stiff-knee gait
- Scissoring gait
- Foot deformities
- Walking problems due to abnormal postures of the foot

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## Spasticity

Spasticity and contracture are complications that frequently result from neurological injury. They occur when electrical messages from the brain don't coordinate muscles correctly. In the normal situation muscles move joints. For each muscle, there is a "gas pedal" and a "brake" on each side to extend or contract. Sometimes with brain injury, the messages are disrupted and cause one side of the muscle to be over stimulated. This "frayed wire" interrupts the "electrical conduction" and affects the control of muscle movement. If the correct neurological message isn't given to them, muscles can overreact. Spasticity is an increase in the normal reactivity of muscles, leading to unequal forces on the joints. It can create contracture—fixed muscle shortening. When this happens, arms and legs stiffen and "freeze" in one position.



Pre-operative with severe spasticity



Post-operative following surgical correction

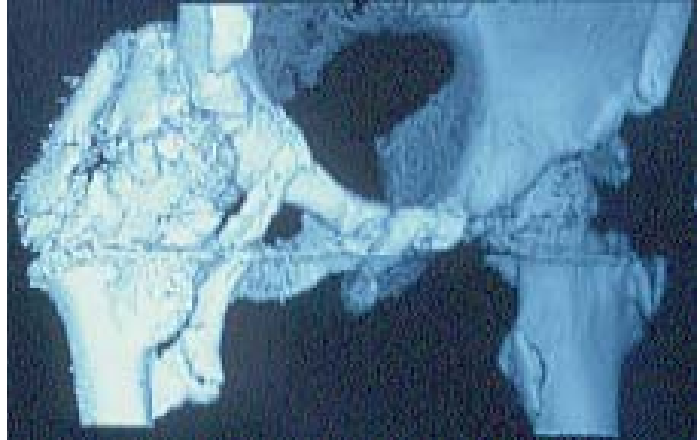
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## Heterotopic Ossification

**H**eterotopic ossification (HO) is the formation of bone in the soft tissues, usually near joints. HO can grow as a complication of injury to the brain or spinal cord. It can also result from severe trauma to an arm or leg. Although, the exact cause of heterotopic ossification is not known, it clearly has a preference for joints surrounded by spastic or weak muscles. While it is growing, HO can cause severe pain and inflammation. HO regularly freezes the joint and must be removed by surgery to restore movement.



Computer generated model of a hip with heterotopic bone blocking motion



CT Scan of a patient with marked heterotopic bone blocking motion.

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## Traumatic Brain Injury

**T**raumatic brain injury is one of the leading causes of injury, disability and death among young people in the U.S. Severity can range from a minor concussion to complete loss of voluntary behavior as seen in coma. Brain injury is at least twice as common in males as in females and occurs most often in people aged from 15 to 24 years. About half of the injuries result from motor vehicle accidents. In the United States, 410,000 new cases of traumatic brain injury can be expected each year, with each case presenting a challenge to the team of health care providers involved in providing emergency treatment and long-term management.

Brain injury is frequently the result of a high-velocity accident. Diagnosis of other injuries is problematic because multiple injuries are common, other lifesaving efforts make a complete examination difficult, and the patient cannot assist in the history or physical examination. Fractures or dislocations are missed in 11% of patients, and peripheral nerve injuries are missed in 34%. Fractures can heal in poor alignment as a result of spasticity.

Heterotopic ossification (abnormal bone growth in the soft tissues near joints) occurs commonly. Spasticity, muscle weakness and contractures are common.

Neuro-Orthopaedic management is aimed at correction of residual limb deformities and excision of heterotopic ossification.



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## Stroke

**S**troke (cerebrovascular accident or brain attack) occurs when thrombosis, embolism, or hemorrhage interrupts cerebral oxygenation and causes the death of nerve cells in the brain. This leads to deficits in cognition and in muscle and sensory function.

In the United States, where cerebrovascular accidents are the leading cause of hemiplegia in adults and the third leading cause of death, there are 2 million people with permanent neurologic deficits from stroke. The annual incidence of stroke is 1 in 1000, with cerebral thrombosis causing nearly three-fourths of the cases. More than half of stroke victims survive and have a good life expectancy. Most survivors have the potential for significant function and useful lives if they receive the benefits of rehabilitation.

The typical clinical picture following stroke is called spastic hemiplegia. Hemiplegia refers to paralysis and spasticity of either the right or left side of the body. There is usually more paralysis in the arm than in the leg. Because hand function requires relatively precise motor control, even for activities with assistive equipment, the prognosis for the functional use of the hand and arm is considerably worse than for the leg. Return of muscle control in the leg is often sufficient for walking.

After stroke, recovery follows a fairly typical pattern. Most recovery occurs within 6 months, although functional improvement may continue as the patient learns to cope with disability. Initially after a stroke, the limbs are completely flaccid. Over the next few weeks, there is a gradual increase in muscle tone and spasticity in the muscles of the shoulder, elbow, wrist, and fingers. Spasticity also develops in the leg muscles. Most commonly, there is an extensor pattern of spasticity in the leg, characterized by scissoring of the legs, a stiff knee, and deformities of the foot and ankle. In some cases, however, there is a flexion pattern of spasticity, characterized by hip and knee flexion.



Equinovarus foot deformities are common after stroke and brain injury. This deformity is easily corrected with tendon transfer surgery. A normal foot posture makes standing and walking possible for many patients.

Neuro-Orthopaedic management is aimed at correction of the limb deformities that result from stroke. Most commonly this means surgical correction of foot problems to aid in walking. Hip, knee and arm problems can also be corrected to improve the quality of life of stroke survivors.

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## Cerebral Palsy

Cerebral palsy is a non-progressive and non-hereditary disorder of impaired muscle function. The onset may be prenatal, perinatal, or postnatal. An exact cause is not always known, but the impairment is sometimes associated with prematurity, perinatal hypoxia, cerebral trauma, or neonatal jaundice. In the United States, over 500,000 people are affected by cerebral palsy. The degree of neurologic impairment is severe in one-third of patients and mild in about one-sixth.



Flexion contractures of the hips and knees cause a crouched posture. This makes standing and walking very difficult. The patient must lean heavily on his arms for support to stand upright.

Spastic diplegia is seen in 50–60% of cerebral palsy patients in the United States and is the most common neurologic pattern. It is characterized by major involvement in both lower legs with only minor incoordination in the arms. Pediatric orthopaedic surgeons and rehabilitation specialists treat children with cerebral palsy. Advances in the treatment of children using temporary muscles and nerve blocks for spasticity have made orthopaedic surgery less common.

The adult patient with cerebral palsy often has long-standing deformities, which may be rigid. A crouch gait posture is a common problem. This results from flexion contractures of the hips and knees. The crouched posture makes walking extremely energy inefficient and often results in a person becoming bound to a wheelchair. Surgical correction of the hips and knee contractures can improve posture and walking.

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## Spinal Cord Injury

**T**rauma to the spinal cord causes dysfunction of the cord, with loss of sensation and muscle function. There are approximately 400,000 patients with spinal cord damage in the United States, and the incidence rate is estimated to be 10,000 per year. The leading causes of spinal cord injury are motor vehicle accidents, gunshot wounds, falls, sports (especially diving) injuries, and water injuries.

Tetraplegia refers to loss or impairment of muscle and sensory function in the cervical (neck) segments of the spinal cord with resulting impairment of function in the arms, trunk, legs, and pelvic organs. Paraplegia refers to loss or impairment of motor and/or sensory function in the thoracic (chest) or lumbosacral (low back) segments of the spinal cord. Arm function is intact but, depending on the level of the cord injured, impairment in the trunk, legs, and pelvic organs may be present.

Prevention of contractures and maintenance of range of motion are important in all patients with spinal cord injury and should begin immediately following the injury. Heterotopic ossification is common in patients with spinal cord injury. The heterotopic bone can freeze the hip joints making sitting, dressing and transferring to and from a wheelchair very difficult. Surgical removal of the abnormal bone will improve mobility. Tendon transfer surgery can improve upper extremity function in patients with tetraplegia.



Surgery restored some use to Sam's hand after his spinal cord was damaged when he fell and injured his neck

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## Post Polio

**P**oliomyelitis is caused by a virus. The initial viral infection most commonly causes minor gastrointestinal symptoms. When the virus gains entry into the nervous system, it attacks the anterior horn cells of the spinal cord and leads to skeletal muscle paralysis.

The last major epidemics in the United States occurred during the early 1950s. Because of effective immunization programs, acute poliomyelitis has now become rare in the developed nations of the world. The paralysis remains a life-long challenge for polio survivors and continues to be a major health problem in the modern world. Orthopaedic surgeons are frequently called upon to treat patients with post-poliomyelitis syndrome.

Of the 1.5 million polio survivors in the U.S. today, more than half are now experiencing the same fatigue, weakness and pain they felt as children with polio. Some are also affected by respiratory problems, including sleep apnea, and often difficulty swallowing. These symptoms, known collectively as post-polio syndrome, result from years of accumulated strain on muscles already weakened by the polio virus.

Penn Neuro-Orthopaedics is one of only a very few medical centers in the United States to offer polio survivors sophisticated diagnosis of, and comprehensive treatment for, post-polio syndrome.

We offer patients with post-polio syndrome a comprehensive evaluation and referral to a range of services as needed. Referral services include electrodiagnostic testing, rehabilitation treatment, neurology, bracing services, physical and occupational therapy and psychological support.

Neuro-Orthopaedics brings hope to these people. Our program offers compassionate care with advanced diagnostics and treatments to help people regain some measure of independence.



Susan had polio as a child. The paralysis led to severe mechanical strains on her joints. She developed knee arthritis with pain and deformity in her paralyzed left leg. She was unable to walk more than a few steps. After a total knee replacement and bracing she is walking without pain.

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## Neuromuscular Disorders

The neuromuscular disorders represent a diverse group of chronic diseases characterized by the progressive degeneration of skeletal musculature, which results in weakness, atrophy (muscle shrinkage), joint contractures, and increasing disability.

These disorders are best classified as motor unit diseases because the primary abnormality may involve the motor neuron, the neuromuscular junction, or the muscle fiber. Two broad categories are considered. Myopathies are diseases of the muscle fibers. Neuropathies are disorders in which muscle degeneration is seen secondary to lower motor neuron disease. Most of the neuromuscular disorders are hereditary, although point mutations may result in spontaneous cases.

Early diagnosis is important not only for initiation of appropriate therapy but also for genetic counseling. Treatment programs are aimed at symptomatic and supportive care. Appropriate orthopedic intervention can significantly increase the functional capacity of patients with neuromuscular disorders.

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### Charcot – Marie – Tooth Disease

Charcot-Marie-Tooth (CMT) disease is the most common of the inherited degenerative diseases of muscle (myopathy). It is generally inherited in an autosomal dominant pattern. Onset of the disease is between the ages of 5 and 15 years.

The peroneal muscles of the leg are affected early in the course of the disease. For this reason, Charcot-Marie-Tooth disease is sometimes referred to as progressive peroneal muscular atrophy. The small muscles of the feet and hands are affected later. Patients usually present with progressive claw toe and high arch (cavus) deformities of the feet. Bracing and surgery are often helpful to manage these problems.



Fran developed severe deformities of her feet from CMT. She is seen here after the right foot was corrected with surgery. She later underwent successful surgery for her left foot also.

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## Peripheral Nerve Injuries

Injury to the major nerves in the arms or legs leads to weakness and paralysis. Often these nerve deficits are permanent. Although the nerve action may be lost, the functional use of the limb can often be improved with reconstructive surgery such as tendon transfers. In tendon transfers muscle forces are redirected to regain lost use.

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## Joint Replacement Surgery for Persons with Neurologic Disorders

The demographics in United States are changing with the average age of population increasing. This, coupled with advances in medical care, means more people living longer with chronic neurologic disorders such as multiple sclerosis and Parkinson's Disease. Advances in medical care also results in persons living longer after cerebrovascular accidents (brain attack). Improvements in acute trauma and neurosurgical care are leading to more persons surviving multiple trauma with brain injury. The proliferation of fertility programs means a higher incidence of multiple births. The incidence of cerebral palsy increases with multiple births.

More people of advancing age with significant neurologic impairment are developing degenerative arthritic changes that require consideration of joint replacement. This is no longer a novelty situation but rather a serious challenge to the orthopaedic surgeon. Joint replacement in people with paralysis and spasticity requires a good understanding of the neurologic disorder as well as the orthopaedic issues.

Successful joint replacement in persons with upper motor neuron disorders that cause spastic paralysis requires an understanding extent of volitional muscle control. Common upper motor neuron disorders include traumatic brain injury (TBI), stroke, cerebral palsy, and multiple sclerosis.

It is important to distinguish static from dynamic deformities prior to surgery. In many instances there is a need to stage the surgical procedures and treat soft tissue deformities first. Deformities in other lower extremity joints will affect the mechanics of the arthritic joint in question. For example, a contracture of the ankle which places the foot in a toe down position (Equinus) causes a backwards knee force with each step. Another example is a contracture of the hip into a scissoring position (Hip Adduction) results in pelvic obliquity and an apparent leg length discrepancy.

The peri-operative management of neurologic patients is also very important. Post-operative pain causes a significant but temporary increase in spasticity. This often requires special treatment. Short-term memory problems may be present. Upper extremity involvement may limit ability to use assistive devices such as walkers or canes in the post-operative period. Comprehensive rehabilitation programs are needed.

Special considerations are equally important in patients with flaccid paralysis and weakness. Common lower motor neuron disorders that result in a flaccid type of weakness include poliomyelitis and peripheral nerve palsies. In these people their muscle control is intact but muscle weakness may be widespread. Sensation is intact in polio but may be impaired in peripheral nerve palsies. The deformities seen with flaccid paralysis are static

in nature. The patient may have either contracture from muscle imbalance or instability from weakness.

The patient with a flaccid type of paralysis also has special peri-operative needs. Post-operative bracing may be an integral part of the overall management plan. Upper extremity involvement may limit ability to use assistive devices such as walkers or canes in the post-operative period. Comprehensive rehabilitation programs are needed.

## Service Director

### **Mary Ann E. Keenan, MD**

Chief, Neuro-Orthopaedic Service  
Professor of Orthopaedic Surgery

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### **Undergraduate Education**

University of Pennsylvania: General Honors Program

### **Medical School**

The Medical College of Pennsylvania

### **Residency Program**

Orthopaedic Surgery, Albert Einstein Medical Center

### **Fellowships**

Arthritis and Joint Replacement Surgery  
Neuro-Orthopaedic Surgery  
Rancho Los Amigos National Rehabilitation Center

### **Fellowship: Area of Concentration**

Neuro-Orthopaedic Surgery

### **Previous Faculty Appointments**

University of Southern California  
Temple University  
Thomas Jefferson University

### **Year Appointed to Penn Faculty**

2002

### **Areas of Expertise**

Surgery for Spastic Limb Deformities  
Heterotopic Ossification  
Post-Polio Syndrome  
Joint Replacement for Neurologic Patients

### **Areas of Special Interest**

Reconstructive orthopaedic surgery for persons with traumatic brain injury, stroke and other neurologic disorders

