DOCUMENT RESUME

03758 - [B2934205]

Cost of Spinal Cord Injuries in the United States and Progress in Spinal Cord Regeneration. HRD-78-10; B-164031(2). October 14, 1977. 42 pp.

Staff study.

Issue Area: Health Programs (1200).
Contact: Human Resources Div.
Budget Function: Health: Health Research and Education (552).
Organization Concerned: Department of Health, Education, and Welfare; Veterans Administration.

A study was conducted of spinal cord injury costs in the United States and current research efforts involving spinal cord regeneration. The consequences of a spinal cord injury range from partial paralysis to death. A victim who survives incurs lifetime medical costs that can range between $44,000 to $115,000 depending on the extent of the injury, not to mention the lost earnings and other injury related costs. Advances have been made in diagnosing spinal cord injuries and treating damage to the cord caused by pressure on the spine. However, once the cord's nerve fibers are destroyed, function below the level of the injury is usually lost and no treatment available can regenerate nerve fibers. Regeneration research to date has not been successful in regrowing nerve fibers in humans for numerous reasons. Many Federal agencies are studying the problem with no central direction and are supporting various approaches to solve the problem. In England special centers have been developed to treat spinal cord injuries and the concept has been accepted throughout Europe. (Author)

03758 4205

STUDY BY THE STAFF OF THE U.S. GENERAL ACCOUNTING OFFICE

Cost Of Spinal Cord Injuries In The United States And Progress In Spinal Cord Regeneration

The consequences of a spinal cord injury can be devastating-- from partial paralysis to death. A victim who survives incurs lifetime medical costs that can range between $44,000 to $115,000 depending on the extent of the injury, not to mention the lost earnings and other injury related costs.

Advances have been made in diagnosing spinal cord injuries and treating damage to the cord caused by pressure on the spine. However, once the cord's nerve fibers are destroyed, function below the level of the injury is usually lost and no treatment available can regenerate nerve fibers.

In England, special centers were developed to treat spinal cord injuries and the concept has been accepted throughout Europe. This concept consists of establishing acute spinal cord injury centers throughout the country staffed with a multi-disciplined team of medical specialists. This approach should be more widely used in the United States, according to medical authorities, while research on regenerating the spinal cord continues.

Regeneration research to date has not been successful in regrowing nerve fibers in humans for numerous reasons. Many Federal agencies are studying the problem with no central direction and are supporting various approaches to solve the problem.

HRD-78-10

OCTOBER 14, 1977

Contents

ABBREVIATIONS

GAO	General Accounting Office
IIHS	Insurance Institute for Highway Safety
NIH	National Institutes of Health
NINCDS	National Institute for Neurological and Communicative Disorders and Stroke
NPF	National Paraplegia Foundation
NYU	New York University
PVA	Paralyzed Veterans of America
RSA	Rehabilitation Services Administration
SCI	Spinal Cord Injury
VA	Veterans Administration

CHAPTER 1

INTRODUCTION

In a letter dated October 8, 1976, five members of the Congress from Oregon requested that GAO conduct a study of spinal cord injury (SCI) costs in the United States and current research efforts involving spinal cord regeneration. We agreed that we would examine other aspects of traumatic spinal cord injuries including annual incidence, prevalence, and causes of such injuries; progress and problems in treatment; the status of efforts to regenerate the human spinal cord after injury; and coordination efforts among the various Federal organizations involved in research in this area.

This staff study included reviewing studies, reported on in the literature, and interviewing officials of the following organizations:

Federal Agencies and Departments

Department of the Army
Department of the Navy
National Aeronautics and Space Administration
National Institutes of Health
National Science Foundation
Rehabilitation Services Administration
Veterans Administration

Private Organizations, Medical Schools, and Hospitals

Insurance Institute for Highway Safety
Institute for Rehabilitation Medicine
National Paraplegia Foundation
Paralyzed Veterans of America
Bellevue Hospital Acute Spinal Cord Injury Center
Case-Western Reserve University
Cornell University Medical School
Johns Hopkins University Medical School

Medical University of South Carolina
New York University Medical Center
Ohio State University Acute Spinal Cord Injury Center
Rancho Los Amigos Hospital
University of Maryland Medical School
University of Michigan
University of Texas Medical School
University of Wisconsin Medical School

We also visited acute SCI centers at Bellevue Hospital, New York, New York and the Veterans Administration Hospital, West Roxbury, Massachusetts. Finally, to identify current spinal cord injury and regeneration research projects, we used data provided by the various Federal agencies and private organizations.

NATURE OF SPINAL CORD INJURY

The spinal cord and the brain make up the central nervous system. The spinal cord is composed of approximately 100 million nerve fibers and cells and is about 17 inches long. It connects the brain with the muscles, skin, and internal organs.

All important motor and sensory functions controlled by nerve messages or impulses that originate in the brain travel along the nerve fibers in the spinal cord.

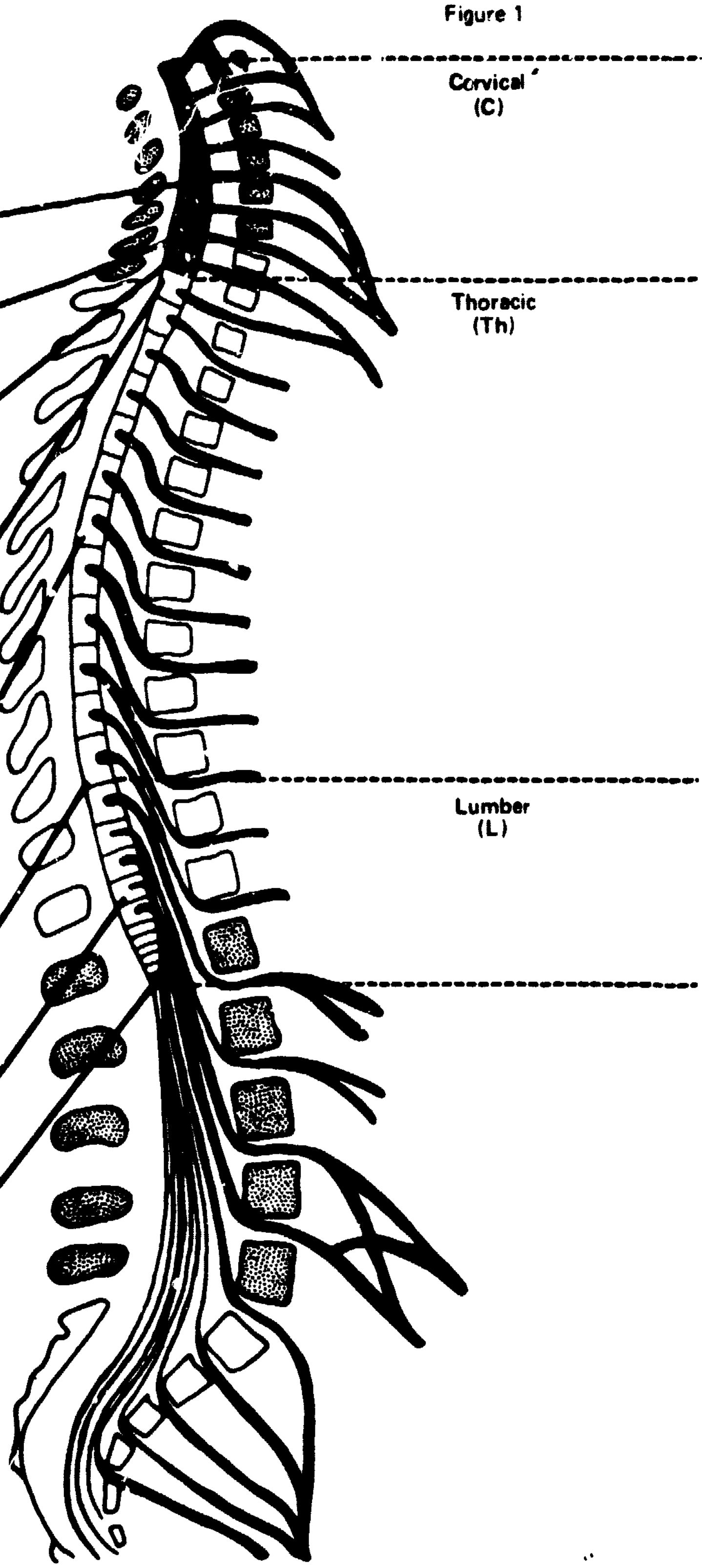
As shown in figure 1, the spinal cord is divided into 31 segments (8 cervical or neck, 12 thoracic or chest and 11 lumbar or lower back) with nerve roots emerging from each segment. These nerve roots carry messages to and from the muscles or other parts of the body. Nerves which connect the central nervous system to other parts of the body make up the peripheral nervous system. Figure 1 also shows the consequences of suffering an SCI by level of injury on the cord.

Internally, the spinal cord is composed of an outer white matter consisting of nerve fibers carrying impulses to or from the brain and peripheral nerves, and an inner gray matter made up of nerve cells. The gray matter has the greatest metabolic activity and is the most sensitive to injury.

The gray matter is composed of nerve cells called neurons. Each neuron consists of a cell body and one or more threadlike projections that may reach a length of several feet. Those projections that receive messages and carry them towards the cell body are called dendrites and those that carry them away from the cells are called axons (nerve fibers). Nerve fibers which have a common origin and common destination are called nerve tracts.

Nerve fibers terminate by branching into many fine filaments called terminals. These terminals establish contact with other cell bodies or organs at a junction called a synapse. The function of the synapse is to transfer chemical

Figure 1



C5 quadriplegia
Reduced respiratory capacity. Patient totally dependent on others. Wheel-chair indispensable.

C7 quadriplegia
Reduced respiratory capacity. Patient almost totally dependent on others. Wheel-chair indispensable. Need for splints and other aids for the forearms and hands.

C8-Th 1 paraplegia
Reduced respiratory capacity. Partial dependence on others but only minimal aid needed for personal care. Wheel-chair indispensable. Crutch gait possible with long leg braces, pelvic band with hip locks and with or without a spinal brace, and two crutches. Possible to drive a car fitted with hand controls and automatic clutch.

Th 1-2 paraplegia
Reduced respiratory capacity. Complete independence. Wheel chair indispensable. Crutch gait possible with long leg braces but not necessarily a pelvic band, and crutches. Possible to drive a car fitted with hand controls but not necessarily with an automatic clutch.

Th 7 paraplegia
Complete independence. Wheel-chair indispensable. Crutch gait possible with long leg braces but not necessarily a pelvic band, and crutches. Possible to drive a car fitted with hand controls.

Th 12-L1 paraplegia
Complete independence. Wheel-chair indispensable. Crutch gait possible with leg braces and crutches. Possible to drive a car with hand controls.

L 4 paraplegia
Complete independence at home and elsewhere. Wheel-chair not indispensable. Normal walking possible with foot braces to counter drop foot, crutches and sometimes knee-stabilizers. Possible to drive a car fitted with hand controls.
Cauda equina

or electrical activity from the neuron to its target in order to transfer the nerve impulse.

The human spinal cord like the brain is unable to replace destroyed nerve cells. When a spinal nerve fiber is damaged it is unable to cross the area of injury and reestablish communication beyond the point of injury. This is in contrast to the peripheral nervous system where severed nerves can grow back and reestablish functional communication. The spinal cord, unlike some portions of the brain, has no spare parts or alternate pathways so that undamaged portions generally cannot take over or be trained to take over the function of the damaged portion.

CONSEQUENCES O SPINAL CORD INJURY

The consequences of spinal cord injury range from partial paralysis to death. An SCI causes an interruption of the nerve messages that are transmitted from the brain down to the skin and muscles and vice versa. Thus, the portions of the body below the level of the injury are left unfeeling, and nonfunctional. Generally, the higher the injury on the spinal cord, the greater the disability.

There are two main categories of SCI, complete and incomplete. Complete lesions are defined as those in which there is a total paralysis of all muscles and a total loss of all sensations below the level of injury. Incomplete lesions are defined as those in which there is preservation of some voluntary movements or sensations below the level of injury. According to NIH and VA officials, injuries to the spinal cord rarely result in complete lesions, and persons sustaining complete lesions rarely show improvement. Generally, persons sustaining incomplete lesions have a better chance for functional recovery.

SCI victims are classified as either paraplegics or quadriplegics. Victims whose lower extremities and abdominal functions are affected are called paraplegics. Their injury is at the thoracic level or below. Victims whose injury is in the cervical region have paralysis of both the upper and lower extremities with effects on body organs such as the lungs. They are called quadriplegics. However, often the term "paraplegic" is used as a general description of a person suffering an SCI, regardless of the level of injury.

The main determinant in recovery of function after an SCI is the level of the injury to the spinal cord. Injuries in the cervical region usually result in quadriplegia with paralysis of both arms and legs and with involvement of bladder and bowel functions. The higher levels, those above the fourth cervical level, are usually fatal.

Persons with injuries at the sixth and seventh cervical level have nearly normal shoulder and elbow function, but diminished hand function. These persons are often able to perform many elements of self care, but are significantly dependent on others. Patients with injuries at the eighth cervical and first thoracic levels have most of their hand functions, but despite paralyzed lower limbs, bowels and bladder can achieve nearly complete independence. Persons with injuries at the second thoracic level and below are parapalegic with normal upper extremity function but paralyzed legs. Their bladder, bowel and sexual functions are also affected. These individuals are capable of complete independence but are confined to a wheelchair. Not until the level of injury is in the mid-lumbar segments is reasonable ambulatory function possible with the help of crutches and foot braces.

The medical complications and functional disabilities of SCI are more serious than might be apparent. Paralysis of the legs does more than prevent walking. It can cause severe and painful muscle contractions, spasticity, and orthopedic deformities. The sensation of pain is lost in the affected area, thus removing a body safety mechanism. Pain signals danger from heat, cold, and pressure. These signals reach healthy persons even while they are sleeping, causing physical reactions. Thus, we change our sleeping position without waking because of the discomfort of skin and body tissues which have been under pressure. We shift our position when awake, too, often without realizing it. Lacking sensation in large areas of his body, both asleep and awake, the paraplegic develops decubitus ulcers (pressure sores) on his buttocks, heels, and other bony parts of his body. A paraplegic's ability to perspire is also impaired. Since perspriation helps to cool the body under conditions of severe heat, the SCI victim is vulnerable to hot weather and to fever caused by mild infections due to his reduced ability to perspire.

Paraplegics may also lose voluntary control of their bowel and bladder functions. Genital sensation may be lost and sexual function impaired. Urinary infections, bladder stones, and gastrointestinal disorders are frequent complications. Bladder catheterization is usually needed, either continuously or on an intermittent basis and catheterization itself can be a cause of infection. Respiratory disorders are also a serious complication and problem for quadriplegics.

Along with the physical disabilities and complications, an SCI victim and his family must cope with emotional problems. The victim may suddenly be dependent on others, often at a time of life when he is at a peak of physical and social independence. Career, financial independence, marriage, family, and social relationships are all changed. Although rehabilitation and a somewhat satisfactory life style are now possible, the patient's own psychological adjustment to his disability is critical to his recovery.

According to NIH and VA officials, most spinal cord injuries are those of contusion (bruising), crushing or destruction due to loss of blood flow. If the spinal cord is compared to a telephone cable containing thousands of wires, damage to the cord is similar to twisting and dissolving of the individual wires with a resultant gap in the cable and a barrier composed of non-conducting material introduced at the location of the damage. In a minority of cases, the cord is transected (cut) at the time of injury and all function is immediately lost.

NIH and VA officials told us that while paralysis is immediate after a traumatic SCI, the pathological processes that result in destruction and death of nerve tissue evolve over a four to six hour period. SCI research showed that during this period circulation is impaired and hemorrhage begins in the central gray matter of the cord. Oxygen levels in the nerve tissues drop and the hemorrhage continues to spread causing cell death. Following this, edema (swelling) forms in the spinal white matter and causes degeneration of the spinal nerve fibers. This degeneration produces an actual gap in the spinal cord nerves. Scar tissue forms at the point of the damage and motor and sensory functions are lost. The process then spreads up and down the spinal cord sometimes involving destruction of brain cells. These officials told us that in order to prevent permanent injury to the spinal cord, this process must be stopped very early in its progression.

Present day SCI research is mainly directed in two areas. The first area of research is called spinal cord injury research and its goal is to limit the degeneration in the spinal cord by preventing the sequence of events that occurs after an injury. The second field of research is directed towards stimulating or encouraging the orderly regrowth of spinal nerve fibers. Such research is called regeneration research. To date, no one has been able to regenerate nerves in the human spinal cord. Progress and problems in spinal cord injury and regeneration research will be discussed in Chapter 5.

CHAPTER 2

EXTENT AND CAUSES OF SPINAL CORD INJURIES

INCIDENCE AND PREVALENCE

Numerous studies have been performed on the extent of spinal cord injuries in the United States with vast differences in their results.

In a study released in 1975, NIH estimated that there were 100,000 victims of traumatic spinal cord injury and nearly 10,000 new cases each year.

In 1974, the National Paraplegia Foundation (NPF), an organization providing primarily information and referral services for paraplegic on matters such as rehabilitation, care, and research, also studied spinal cord injury. NPF estimated that in 1970 there were 46,700 victims of traumatic spinal cord injury alive in the United States and that this figure will increase to 75,2000 by 1980. NPF estimated that 3,190 new cases occurred in 1974.

Also, in 1974, the Rehabilitation Services Administration (RSA) estimated that the total number of SCI victims to be between 100,000 and 125,000. RSA said that 7,000 to 10,000 new cases occur each year.

Studies have shown that young people suffer most from SCI. In 1976, NPF stated that 90 percent of the victims are between the ages of 16 and 30, and a 1974 study by RSA yielded similar results.

CAUSES

We identified seven studies that assessed the causes of SCI. While four of the studies were conducted outside of the United States and were conducted during different time periods (1968-1976) all the studies showed motor vehicle accidents to be the leading causes of SCI. For example, using the results of a 1974 California study, NIH said that motor vehicle accidents account for 56 percent of all acute SCI cases. The table below summarizes the results of the three American studies.

Causes of SCI (in percent)

	Motor Vehicle	Falls	Sports	Assault	Other
NIH (1974)	56	19	7	12	6
Rancho Los Amigos SCI Center, Calif. (1969)	48	12	11a/	19	10
Florida Study (1976)	38	16	21	18	7

a/Diving only

CHAPTER 3

METHODS OF TREATING SPINAL CORD INJURY

At the time of World War I only 10 percent of paraplegics lived for a year after injury according to NIH. Today, 90 percent survive and after one year following the injury their mortality rate only slightly exceeds that of the general population. These results are attributable to a number of factors which are discussed below.

DIAGNOSTIC ADVANCES

Once an SCI victim's condition is stabilized, a thorough neurological examination with specific attention to demonstrating the presence or absence of function in the spinal cord below the injury is the main part of diagnosis, according to medical officials we interviewed. A new development in testing the ability of the spinal cord to function is through "evoked sensory cortical potentials." This technique involves placing recording electrodes on the patient's scalp and stimulating peripheral nerves below the injury. The electrodes pick up any responses and a recorder prints out the results. The primary value of this technique is in distinguishing complete from incomplete injuries.

Another diagnostic advance has come in the development of myelography which is a special technique to photograph the spinal cord. Myelography involves injecting a substance into the area around the spinal cord (called the spinal canal) to enhance X-rays taken of the cord and its soft tissue.

TREATMENT OF INJURY RELATED PROBLEMS

Several clinical advances have been made in treating acute SCI related problems. Injury below the waist often results in loss of bladder and bowel function. Thus, bladder and bowel infections are a problem and urinary tract complications are a major cause of death for paraplegics. The development of antibiotics, the specialty of urology and educating the patient in proper bladder and bowel maintenance have greatly aided in solving these problems.

A major advance in preventing urinary infections is the development of the technique of intermittent catheterization to pass urine. A catheter, which is a tubular instrument used for withdrawing body fluids, is inserted into the bladder through the urethra every six to eight hours. Urine is then withdrawn through the catheter, emptying the bladder. Before the development of this technique, a catheter had to be inserted permanently in the victim. According to the medical officials we interviewed, the catheter itself was often a cause of infection. Medical studies by hospitals using intermittent catheteriztion have shown that 75 to 85 percent of patients were free from urinary infections upon discharge.

Advances in treating bowel problems have consisted mainly of establishing a regular elimination pattern for the patient through a combination of proper diet, massage and rectal stimulation.

Decubitus ulcers (pressure sores) are a serious problem for paraplegics. When a paraplegic remains in the same position for an extended period, the constant pressure of the body's weight will cause the skin to break down and sores to develop. Because of paralysis, the SCI victim can neither perform the shiftings and turnings that are natural to healthy people, nor feel that a sore is developing. Today, this problem can be virtually eliminated, according to medical authorities.

Prevention of pressure sores is based on maintaining good general skin condition and avoidance of prolonged skin pressure. To accomplish the latter, specially designed beds have been developed so that the patient can be turned to relieve pressure while confined to bed and special wheelchairs have been developed to prevent pressure on the patient's skin. In addition, the victim is educated on the necessity of avoiding prolonged skin pressure and the importance of daily inspections of the parts of the body most susceptible to pressure sores.

When a person suffers an acute SCI, the muscles below the injury often are still function but cannot be controlled. This condition is called spasticity. Severe spasticity is treated by either muscle relaxants or surgery. According to a neurosurgeon at the University of Maryland Medical School, surgery to reduce spasticity has an initial success rate of 90 percent, but only about 50 percent of patients having such surgery retain any long term benefit. One of the biggest problems for quadriplegics is muscle calcification (hardening of tissue resulting from calcium deposits), according to a physician at the Institute for

Rehabilitation Medicine in New York. When muscle calcification occurs, motion becomes impossible. These problems have been lessened through improved rehabilitation techniques and returning the patient to activity in a short period of time.

All quadriplegics suffer impairment of respiratory function to some degree because the chest and abdominal muscles are paralyzed. Injuries above the fourth cervical level result in total paralysis of the diaphram and life is not possible without artificial respiratory support within minutes after injury.

TREATMENT OF SPINAL CORD INJURY

According to medical authorities, an SCI is usually caused by an external force on the spine. The force causes the spine to come into contact with the spinal cord and results in damage to the cord. While specific methods of treating damage to the spine causing injuries to the spinal cord have been developed, there are no accepted methods in practice for treating damage to the spinal cord itself.

Treatment used on the individual patient will vary with the level of injury and the amount of damage to the cord. In those injuries involving complete transection of the cord, all that is done is to heal the associated injuries as effectively as possible and prevent the complications which follow paralysis. However, most SCI's are incomplete and the specific modes of treating incomple SCI are discussed below.

Skull traction

Skull traction is used to correct spinal deformity and/or dislocation and immobilize the spine. Several mechanical devices have been designed to provide the traction.

As practiced at the VA Acute Spinal Cord Injury Center in West Roxbury, Massachusetts, skull traction is performed after diagnostic X-rays have been taken. The alignment of the traction is adjusted in accordance with the X-rays. Assuming reduction in the deformity or dislocation is achieved with skull traction, the procedure is continued for one to eight weeks, depending on the level and extent of the injury. X-rays are taken to determine that healing has occurred before the traction is removed.

Spinal fusion

According to VA medical authorities, the primary indications for a spinal fusion operation are the failure of spontaneous healing with abnormal spinal mobility or increasing spine deformity. Fusion is also used with other surgical procedures. The level of the injury and the amount of damage will determine whether the operation is to be performed and if so, the type of operation.

Neurosurgeons at New York University Medical Center and Bellevue Hospital Acute Spinal Cord Injury Center stated that they normally use the fusion operation to realign the vertebrae of the spine. Misaligned vertebrae cause pressure on the spinal cord and increase damage. During the operation, the damaged vertebrae is removed and a piece of bone, taken from the patient's hip, is inserted into the area where the damaged vertebrae was removed. Once this has been accomplished, specially designed steel support rods are inserted into the spine to add stability and to keep the proper alignment. Large doses of steroids are used to reduce swelling.

Laminectomy

A laminectomy is performed to relieve pressure on the spinal cord. It is an operation whereby the bony protective shields along the spine, the laminae, are removed and the vertebrae are realigned and stabilized. Officials at New York University Medical Center, Bellevue Hospital Acute SCI Center, and NIH said that laminectomy may produce increased mobility of the spine. Such mobility, however, may increase contusions and bruises of the spinal cord and could lead to increased neurological damage.

According to VA neurosurgeons, only if diagnostic studies show material pressing on the spinal cord from the spine which correlates with the neurological damage should the laminectomy be performed. Such an approach is shared by NIH authorities. In their opinion, the only reason to perform a laminectomy is to expose the spinal cord for other surgical procedures.

ACUTE SPINAL CORD INJURY CENTERS

Some medical authorities told us that the quality of spinal cord injury treatment in the United States is heavily dependent upon the experience and expertise of the personnel treating such an injury. These officials said that due to the low incidence rates of SCI, it is unlikely that the average hospital will have experienced people trained in dealing with SCI and cognizant of the importance of proper treatment during the first few hours following injury. In order to rectify this situation, some medical officials said that a concept for treating acute SCI developed in England and now accepted generally in Europe should be more widely used in the United States. This concept involves establishing acute spinal cord injury centers throughout the country. These centers were described by the medical officials as a significant advance in treating acute SCI.

The acute spinal cord injury center concept was developed by Dr. Ludwig Guttman, a British neurosurgeon at the Stoke-Mandeville Hospital in England. Guttman's concept begins with early case finding and referrals. It also consists of having highly trained emergency medical service personnel, organized in comprehensive regional systems and provided with proper equipment, communications, vehicles, and easily accessible medical facilities. Once the patient arrives at a center he is treated by a clearly defined team of physicians, surgeons, specially trained nurses, and other professionals ranging from physical therapists to vocational rehabilitation counselors. The patient not only receives services from all these disciplines, directed and coordinated by a single physician in charge of his case, but he receives these services concurrently. From acute care through rehabilitation he is followed by the same team. Rehabilitation services such as physical therapy, psychological counseling, and vocational planning begin as soon as acute medical and surgical procedures are accomplished. The patient is followed steadily by the physicians involved at the acute stage, as well as by specialists such as urologists and orthopedic surgeons.

Some medical officials we interviewed stated that employing the acute SCI center concept does not require a substantial construction program. On the contrary, they said the center should be a part of an existing hospital (preferably a hospital connected or affiliated with a teaching facility, such as a university) with a full complement of medical surgical services.

Medical officials said a spinal cord unit should range from a minimum of 20-30 beds to a maximum of 50-60 beds. Units smaller than 20 beds are unable to ensure a patient turnover rate sufficient to retain an incentive program for the staff. Also. the financial burden on the hospital would be unbearab.e. Units over 60 beds become unwieldy and difficult to manage effectively, according to medical authorities.

One person with sufficient training and experience should direct the spinal cord unit, according to medical officials. This individual should have total responsibility for all aspects of patient care. Because of the numerous problems involved in spinal cord injury cases, a large, well-trained staff with varied and specialized medical and surgical knowledge and special equipment is required.

Close cooperation among the various specialties--general surgery, plastic surgery, orthopedics, neurosurgery, neuorology, urology, internal medicine, psychology, psychiatry, social medicine, physical medicine, vocational counseling and placement, dietetics, and others, is required for success in treatment, according to medical authorities. Since no single specialist in his own field can be expected to master the totality of knowledge required, it is necessary for the chief of the spinal cord injury center to be trained in a multi-disciplinary approach which will allow him to be knowledgeable most areas and to properly evaluate each situation. Ideally, any chief of the spinal cord injury center should be capable of leading a team of specialists who, because of their own speciality, cannot have a general overview of all the problems involved with a given patient.

According to NPF, Dr. Guttmann's concept has been very effective in returning many patients to functional independence. According to medical officials we interviewed, the acute SCI center concept provides the best possible medical care for a patient. However, medical officials stated very few patients suffering acute SCI in the United States are treated at these centers. Medical officials told us the reasons for this are because there are too few acute SCI centers in the United States and the general public and the medical profession are not aware of this treatment concept. We attempted to develop a comprehensive listing of the facilities in this country having acute SCI centers, but were unable to do so. None of the Federal agencies nor organizations we contacted has this information. However, the facilities listed below are ones we identified in our review as having acute SCI centers.

In addition to the facility at Bellvue Hospital, 1/ we found that NIH currently supports research at acute spinal cord injury research centers located at Ohio State University; Yale University; St. Joseph's Hospital and Medical Center, Phoenix, Arizona; the Medical University of South Carolina, New York University; and Albany Medical College. However, NIH funds provided to these centers are for research on spinal cord injuries and regeneration, not for clinical care or rehabilitation of patients. In September 1977, NIH initiated a new program on a pilot basis to evalute the efficacy of therapy to the spinal and head injured patient. This program of Comprehensive Central Nervous Trauma Centers includes six contracts totaling $625,000 in fiscal year 1977.

The Veterans Administration has 18 facilities designated as spinal cord injury centers. However, VA officials told us that only four of their facilities (West Roxbury, Massachusetts; Palo Alto, California; Wood, Wisconsin; and Tampa, Florida) are capable of treating acute SCI. The rest provide primarily long-term nursing care. Further, VA officials told us that the only facility actually treating acute SCI is the one at West Roxbury.

1/ Bellvue Hospital Acute SCI Center is not funded by NIH.

CHAPTER 4

COSTS OF SPINAL CORD INJURIES

We identified three recent studies by private organizations that assessed the costs of spinal cord injuries. The Paralyzed Veterans of America (responsible for representing veterans' claims before the Veterans Administration) issued a study in 1973, the National Paraplegia Foundation issued a study in 1974, and the Insurance Institute for Highway Safety (attempts to identify and reduce losses resulting from motor vehicle accidents) issued a study in 1976. 1/ NIH is studying the costs of SCI, but its report was not completed in time to be considered in our study. The NIH study was the only one we could find that was being done by the Federal Government on the costs of spinal cord injury.

We utilized the above studies to provide estimates of the cost of SCI.

The studies showed vast differences in the estimated costs of SCI. These differences are due to a variety of factors:

--there are no accurate figures on the incidence or prevalence of spinal cord injuries, so total costs are difficult to estimate,

--costs per individual vary with level of injury, age and sex; and the studies approached these matters differently,

--costs were not projected for a uniform period of time in all the studies,

--the same cost categories were not included in each study, and

--the Paralyzed Veterans of America study used 1973 as a base year for estimated costs while 1974 was used for the National Paraplegia Foundation and the Insurance Institute for Highway Safety studies.

1/The study performed by the Insurance Institute for Highway Safety dealt only with the costs of spinal cord injuries resulting from motor vehicle accidents. We are reporting its findings because motor vehicle accidents have been shown to be the major cause of spinal cord injuries.

For the reasons cited, we found it very difficult to assess the accuracy or reliability of the figures contained in the studies.

COST COMPONENTS

The cost studies we reviewed identified the following cost components of acute spinal cord injuries:

Direct Costs

Emergency Assistance
Hospitalization
Physician Fees
SCI Center Staff Costs
SCI Center Capital Costs
Medical Equipment and Home Modifications
Vocational Rehabilitation
Miscellaneous Supplies and Services
Nursing and Attendant Care
Other Medical and Drug Costs
Rehospitalization

Indirect Costs

Lost Earnings
Psychic Costs
Insurance Administration Costs
Legal and Court Costs

The direct costs of a disease or injury are the expenditures associated with the treatment of that disease or injury. According to IIHS, spinal cord injuries are characterized by high initial hospitalization costs and significant health related maintenance charges that accrue over the lifetime of the patient. Collectively, these costs constitute the direct costs of the injury.

Indirect costs are defined as the lost output or productivity of the victim during his disablement. Indirect costs represent an economic loss to society as well as a personal economic loss to the SCI victim and his dependents. While the NPF and IIHS included indirect costs in their estimates, both such costs. The PVA did not estimate indirect costs of SCI.

We identified the various components of SCI indirect costs. Of the four components which are listed above, both the NPF and IIHS agreed that lost earnings--the value of an

SCI victim's expected future earnings lost because of injury--is the largest contributor to indirect costs. However, the studies differed in how lost earnings should be determined.

A discussion of the various direct cost components associated with SCI follows. The [illegible] which appears on page 25 summarizes the total lifetime direct costs of SCI as reported in the studies. We did not attempt to estimate indirect costs because such estimates are highly speculative.

DIRECT COSTS

Emergency Assistance

Prior to hospital admission, SCI patients may incur emergency assistance costs. These include the costs of: police and fire assistance; emergency transportation to the hospital, and emergency medical treatment upon arrival at the hospital. IIHS estimated these costs would total $400. NPF and PVA did not report this as a separate cost item.

Initial Hospitalization

According to NPF, hospitalization costs include hotel services, nursing, ancillary services (operating room, laboratory work) and general overhead costs. All three studies estimated hospital costs per SCI patient by multiplying the average hospital expense per patient day times the average length of stay of SCI patients.

While all three studies agreed on how initial hospitalization costs should be determined, the studies differed greatly in the estimates of these costs. These differences are due to the range in the length of hospital stay used for an SCI patient, and differences in costs included as a part of hospitalization.

PVA estimated that the average length of hospital stay for an acute SCI patient to be 120 days and the total hospitalization costs to be $18,000. NPF estimated the average length of stay to be 182 days and hospitalization costs to total about $32,8000. IIHS estimated the average length of stay to be between 104 and 235 days (depending on the extent of the injury) and total hospitalization costs to be between $15,600 and $38,540.

Physician Fees

During initial hospitalization, there would be fees for the attending physician, neurosurgeon, and other consultants, according to NPF. NPF estimated these fees to total $1,800 and PVA estimated them to be $1,500. IIHS did not report physician fees as a separate cost item, but included these costs as a part of initial hospitalization expenses.

SCI Center Staff Costs

In addition to the staff of physicians, nurses, and other personnel whose services are provided in a general hospital, patients at an acute SCI center are treated by a team of medical and health professionals in many disciplines. NPF reported these costs as a separate item in their study, while IIHS and PVA did not. NPF estimated these costs would total $8,200 per patient. These costs would not usually be incurred if the patient is treated at a general hospital.

SCI Center Capital Costs

In addition to estimating SCI center staff costs, NPF stated that the cost of building and equipping an SCI center must be apportioned to the patient. These costs would not be incurred if the patient was treated at a general hospital. NPF estimated these costs at $1,400 per patient. The other two studies did not identify capital costs separately.

Medical Equipment and Home Modification Costs

Because of the loss of voluntary motor function in their extremities, SCI patients need prosthetic equipment, medical appliances, and certain modifications to their homes in order to function. Such items as wheelchairs, leg braces, and hospital beds are needed in order to perform activities of daily living. In addition, narrow doorways and small bathrooms may require modification in order for the SCI victim to function in his home. Kitchen appliances may have to be adjusted, the bed may have to be lowered to make wheelchair transfers, and closet rods and doors may have to be adjusted to facilitate dressing. Further, lowering doorknobs, light switches, and telephones, plus raising electric outlets may be necessary to aid activity throughout the home. The type, number, and thus the costs of medical equipment and home modifications vary according to the patient's level of injury, with quadriplegics usually incurring more costs than paraplegics, according to IIHS.

IIHS estimated average home modification costs to be $2,850 for a paraplegic and $6,400 for a quadriplegic. In addition, IIHS estimated average annual equipment costs (includes amortized purchase costs and expected repair costs) to be $210 for a paraplegic and $420 for a quadriplegic with no estimates of the total expected lifetime costs.

PVA estimated home modification costs to be $4,000 or $8,000 depending on injury level and initial equipment costs were estimated at $500 or $1,000. PVA estimated annual equipment replacement and maintenance costs at $300 with no estimates of total lifetime costs. NPF grouped equipment and home modification costs together. NPF estimated these costs to initially total $4,900 but did not estimate annual or lifetime costs.

Vocational Rehabilitation

According to NPF and IIHS, most SCI victims need to reassess their vocational status and to modify their future career plans. To do this, SCI victims need some type of vocational rehabilitation. IIHS estimated that 48 percent of quadriplegics and 63 percent of paraplegics undergo vocational rehabilitation and that this training begins anywhere from three to 18 months after the patient is discharged from the hospital.

IIHS estimated vocational rehabilitation costs at $2,180 for a paraplegic and $3,540 for a quadriplegic. NPF estimated these costs at $5,000 with no distinction for level of injury. PVA did not report vocational costs separately.

Miscellaneous Supplies and Services

According to IIHS, spinal cord injury victims incur costs for miscellaneous supplies and services. Costs in this category include unusual or special expenses for transportation, laundry, bedding, clothing, and non-medical appliances such as electric typewriters and air conditioners.

In the case of transportation, SCI patients who can drive require the installation of hand controls in their automobiles. Those patients who are either unable or unmotivated to drive may require taxi and chauffeur services and quadriplegics may require a specially outfitted van equipped to allow easy passenger entrance and exit.

Uncontrolled bowel and bladder problems and the long periods of time an SCI patient may have to spend in bed all contribute to increases in laundry and bedding expenses.

IIHS estimated the annual costs of these miscellaneous supplies and services at $490 for a paraplegic and $530 for a quadriplegic. The only comparable item that PVA reported in this category was transportation costs which it estimated at $1,000 for a paraplegic and $2,000 for a quadriplegic. NPF did not report these costs separately, but included some in other categories.

Nursing and Attendant Care

Following discharge from the hospital, some SCI patients require continuing assistance, according to IIHS. While paraplegics can manage with minimal assistance, quadriplegics may need assistance in eating, dressing, changing bed position, transferring from bed to wheelchair, and performing other bodily functions. The manner in which this assistance is rendered is related to the extent of injury of the victim. An SCI victim may be placed in a nursing home or chronic care hospital, receive attendant care at home, or require virtually no assistance. IIHS reported that 16 percent of quadriplegics and 6 percent of paraplegics receive permanent institutional care. NPF reported that approximately 75 percent of SCI victims live at home with attendant care. According to NPF, the main difference resulting from treatment in an acute SCI center as opposed to a general hospital is the functional level regained by the victim. NPF stated that the majority of non-SCI center treated patients require some form of nursing care for the rest of their lives whether it is provided by an institution or family. In contrast, the majority of SCI center patients become functionally independent and employable, according to NPF.

IIHS estimated the annual costs of nursing and attendant care to range from $790 to $1,000 for a paraplegic and $2,840 to $7,730 for a quadriplegic. IIHS gave no estimates of the lifetime costs of nursing and attendant care.

Using a complex formula, NPF stated that nursing costs per year amounted to $7,500 for an SCI victim. Adjusting for dependency and injury levels and years of life expectancy, NPF estimated the average total lifetime costs of nursing and attendant care to be $25,600 or $59,700 depending on whether the victim received initial treatment in an acute spinal cord injury center or general hospital. PVA did not provide estimates of these costs.

Other Medical and Drug Costs

Regardless of their functional status, SCI patients are vulnerable to disease and complications from their injury. The majority of medical and drug costs, according to IIHS, are determined by the extent of bowel and bladder impairment. Further, quadriplegics suffering paralysis in the upper part of their bodies run the risk of pneumonia and other pulmonary ailments. All of these problems translate into an increased demand for medical supplies and drugs.

IIHS estimated annual medical and drug costs to be $800 for paraplegics and $1,200 for quadriplegics. IIHS gave no estimate of the lifetime costs under this category.

NPF also reported costs under this category, but included rehospitalization and treatment expenses in their calculations. NPF reported medical costs at $1,500 per annum and $17,100 for a patient's lifetime.

PVA estimated annual medical and drug costs at $700 with no estimate of total lifetime expenses.

Rehospitalization

According to IIHS, even after an SCI victim has been discharged from the hospital and rehabilitated, there is the possibility of rehospitalization. Rehospitalization may be required for the previously mentioned complications that could result from SCI.

IIHS reported that very little data exists on the frequency of rehospitalization of SCI patients and thus it is difficult to project rehospitalization costs. However, from the little data that was available and judgmental assessments of medical and cost experts in the spinal cord field, IIHS stated that annual rehospitalization ranges from two to 15 days per patient with an annual cost ranging between $300 and $2,460. PVA reported annual rehospitalization costs of $2,100. NPF did not provide a separate estimate of rehospitalization costs but included these costs as a part of medical and drug costs.

Lifetime Direct Costs of SCI

All three studies estimated the total lifetime direct costs for a victim of SCI with vast differences in results. The following table displays the figures included in each study.

ESTIMATED LIFETIME DIRECT COSTS OF SPINAL CORD INJURY VICTIMS TREATED IN AN ACUTE SCI CENTER

	IIHS	NPF	PVA
Emergency Assistance	$ 400	-	-
Initial Hospitalization:			
Paraplegic	15,600		
Quadriplegic	38,540	$32,800 a/	$18,000 a/
Physican Fees	-	1,800	1,500
SCI Center Staff Costs	-	8,200	-
SCI Center Capital Costs	-	1,400	-
Medical Equipment and Home Modification Costs			
Paraplegic	2,850 b/	-	4,500 c/
Quadriplegic	6,400 b/	4,900 a/	9,000 c/
Vocational Rehabilitation			
Paraplegic	2,180	-	
Quadriplegic	3,540	5,000 a/	-
Misc. Supplies and Services			
Paraplegic	490 e/		1,000 d/
Quadriplegic	530 e/	-	2,000 d/
Nursing and Attendant Care			
Paraplegic	790-1,000 e/		
Quadriplegic	2,840-7,730 e/	25,600-59,700 a/f/	-
Other Medical and Drug Costs			
Paraplegic	800		
Quadriplegic	1,200	17,100 a/g/	700 a/e/
Rehospitalization	300-2,460 e/ h/	-	2,100 e/
	$44,040-119,480 i/	$96,800-111,400	$115,000 i/

a/No breakdown between paraplegia and quadriplegia provided.
b/Does not include annual equipment and maintenance costs of $210-$420.
c/Does not include annual equipment and maintenance costs of $300.
d/Includes only transportation costs.
e/Only per annum costs.
f/Amount determined by treatment facility initially used - SCI center or general hospital.
g/Includes only hospital and treatment costs.
h/Range determined by length of rehospitalization used (2-15 days)
i/Totals cannot be determined by adding costs in schedule due to different methods used in reporting data.

CHAPTER 5

PROGRESS AND PROBLEMS IN SPINAL CORD INJURY AND REGENERATION RESEARCH

Regeneration of the spinal cord is an attempt to regrow nerve fibers to restore body motor function and sensation. Until recently it was accepted medical theory that the spinal cord was incapable of regeneration. According to medical researchers at NIH, recent research has shown that the spinal cord may be capable of regeneration. According to medical authorities, however, the following problems need to be solved before regeneration can be accomplished:

--nerve cells must survive both the immediate trauma of SCI and the destructive changes that occur after the injury,

--nerve cells must initiate and sustain growth along the nerve tracts,

--nerve fibers must be able to cross abnormal terrain such as the dense scar tissue which forms at the site of the injury creating a nearly impenetrable wall which causes the few fibers that could be induced to cross the scar to be choked off and killed, and

--the nerve fiber must establish "functional recognition" whereby it meets the correct target and establishes proper function--electrical attraction, chemical attraction, or a combination of the two have been suggested as the guidance mechanism.

Research on the spinal cord has been primarily directed at solving these problems and, as a result, has evolved into spinal cord injury and regeneration research.

PROJECTS FUNDED ON SPINAL CORD INJURY AND REGENERATION RESEARCH

We identified three organizations currently supporting research in the area of spinal cord regeneration and spinal cord injury. 1/ The National Institute for Neurological and Communicative Disorders and Stroke (NINCDS) oversees such research at NIH and provides most of the funds for government supported research in these areas. VA is the only other government agency, and the Paralyzed Veterans of America is the only private organization we found supporting research in these areas. NINCDS was supporting both intramural and extramural research at the time of our review. VA was supporting only intramural projects and PVA was supporting only extramural projects. We obtained data on the number of research projects and related funding amounts for the three agencies. To make the figures more meaningful we categorized the projects as follows:

--spinal cord regeneration research--research directly related to spinal cord regneration;

--spinal injury research--research aimed at preventing the progressive post-injury nerve fiber degeneration, and

--related research projects relevant to spinal cord research but having less of a direct application to the areas of regeneration and spinal injury.

The following table shows a total of 100 projects supported in the amount of about $6.5 million. The research projects funded by NINCDS and VA are for fiscal year 1976. PVA's data is cumulative for fiscal years 1972 through 1976.

1/ In addition to the agencies listed above, our review showed that several other Federal agencies have either supported spinal cord injury and regeneration research in the past or have dealt with aspects related to SCI such as electronic prosthesis and stimulation research or peripheral nerve regeneration. This matter will be discussed in a subsequent part of this study. See pages 41 to 42 for a discussion of the other agencies dealing with these areas.

SPINAL CORD INJURY AND REGENERATION RESEARCH EXPENDITURES FOR FISCAL YEAR 1976

	NINCDS			VA		PVA 1/	
	Intramural projects	Extramural projects	Amount	Intramural Projects	Amount	Intramural	Amount
Spinal cord regeneration research	6	29	$2,054,900	4	$174,640	6	$101,960
Spinal injury research	3	12	2,593,234	9	376,685	-	-
Related research	2	25	1,103,818	4	123,079	-	-
Total	11	66	$5,751,952	17	$674,404	6	$101,960

1/ Data for the Paralyzed Veterans of America is cumulative for fiscal years 1972 through 1976.

Grant applications recommended for approval but unfunded

According to NIH officials, the following projects were approved as having scientific merit but unfunded due to a lack of funds during the period June 1975 to September 1976.

	Projects	Amount
Spinal cord regneration	3	$ 72,489
Spinal injury research	13	520,609
Research related to spinal injury and regeneration	4	172,139
Total	20	$765,237

VA and PVA did not have projects awaiting funding because they initiate proposals for research. Proposals for NIH extramural research usually are not initiated in-house.

Increased funding

An NINCDS official and other medical authorities said that a sudden upsurge of funding would not guarantee rapid advances in spinal cord injury and regeneration. The NINCDS official emphasized that solving spinal cord injury and regeneration research problems is not only a matter of increased research funds, but of equal importance is training researchers in the field of spinal cord injury and regeneration. He told us that not many facilities nor researchers are presently available that can undertake this type of research, and NINCDS has no designated training program for spinal cord injury and regeneration. He estimated that an additional $5.5 million could be beneficially used in the spinal cord injury and regeneration area in fiscal year 1978. Of the additional $5.5 million increase in funds, $500,000 could be used by NINCDS to begin a training program and $5 million could be used to award targeted research grants.

SPINAL CORD INJURY RESEARCH

Spinal cord injury research is aimed at prevention of the progressive degeneration of the spinal cord after injury. In theory, if the structure of the nerve tracts can be preserved then function will not be lost. According to medical authorities, this research is based on the following factors:

--The spinal cord, in most patients, is not cut initially but merely bruised or contused. Shortly after injury the cord is still structurally intact;

--Hemorrage and swelling in the cord over a period of hours after injury will lead to progressive degeneration of the nerve fibers;

--Complete degeneration will result in actual structural discontinuities (gaps) in the nerve fibers connect in the spinal cord;

--The degenerative mechanisms that are thought to occur following injury are not well understood;

--Regeneration and restoration of functions will be easier to accomplish if the degenerative processes are stopped as soon as possible because there will be fewer structures to restore.

Medical authorities stated that the possibility of successful treatment of SCI has been enhanced by the discovery that irreversible paralysis does not occur at the time of injury (unless the cord is severed) and that the best possibility for recovering from SCI occurs when the victim is properly treated within 4 to 6 hours after injury. In an experimental setting, the components of the complex biochemical reaction leading to nerve fiber degeneration have been modified by a variety of physical and pharmacological means resulting in a lessening of the destruction and some degree of preservation or return of function.

Physical attempts used to prevent degeneration include hyperbaric oxygen, cooling of the cord, and myelotomy (incision of the spinal cord). Hyperbaric (high pressure) oxygen is infused into the tissues of the cord to increase its oxygen concentration, based on the theory that decreased blood flow in the cord starves it of oxygen. Lack of oxygen may cause degeneration of nerve tissue. Cooling of the cord is accomplished by an operative procedure which exposes the spinal cord. It is then irrigated with a saline solution in an effort to slow the cord metabolism and prevent swelling. Myelotomy has been attempted, on a trial basis, at the Bellevue Hospital Acute Spinal Cord Injury Center, in an attempt to provide internal decompression of the cord. An incision directly into the cord theoretically will release the pressure caused by swelling. In order to perform a myelotomy, a laminectomy must first be performed to expose the cord. The cord is then incised and the fluids causing tissue death are released. This technique is new and its benefit in treating SCI is not established.

Pharmacological (drug) therapy used in an attempt to prevent cord degeneration includes steroids and chemical agents to lessen bleeding and prevent clotting. Drug therapy is based in part on the hypothesis that drugs (including alcohol) have been proven to enhance the post-injury degenerative processes, according to NIH officials. Therefore, drugs may be beneficial in reversing this process. Steroids have been used in the clinical setting in increasing doses to prevent swelling. Surgeons at Bellevue Hospital Acute SCI Center have recently increased the amounts of steroids used on spinal cord injury victims because lower doses commonly in use had inconclusive results. Chemical agents to lessen bleeding have been used to try to lessen hemorrhage by slowing blood flow. Similarly, hormones have been used to decrease the possible traumatic effects of other chemicals produced by the body as a result of the spinal cord injury. Neither approach has shown positive results.

With the exception of limited success in the use of myelotomy and steroids, demonstration of the beneficial results in the laboratory have not been translated into successful clinical treatment of spinal cord injury. Medical authorities stated that the reasons for discrepancies in laboratory results and clinical application may be due to the experimental model being used which is an exposed animal's spinal cord, subjected to injury and treated almost immediately. In most actual injuries involving humans, the cord is not exposed because it is encased in the body cavity and protected by the spine. In addition, there is usually a delay between the time of injury and treatment in humans. Medical authorities also said that the discrepancies may be due to differences between human and nonhuman spinal cords.

REGENERATION RESEARCH IN THE UNITED STATES

In 1973 the Director of the NINCDS appointed an ad hoc subcommittee on growth and regeneration in the central nervous system of the NINCDS national advisory council. This subcommittee was charged with reviewing and evaluating the status of research on regeneration and to identify areas of research where opportunities for advances existed.

A series of scientific workshops was sponsored by the subcommittee in which scientists from all over the country participated. Subsequently the subcommittee prepared a report in 1975 which summarized the results of the scientific meetings and made recommendations to the council in three general categories: (1) high priority research areas, (2) training, and (3) planning and coordination.

The high priority research areas evolved from research which showed that abortive central nervous system regeneration occurred in mammals but that function is almost never recovered except in simpler creatures. The subcommittee stated that investigation of the biological ryles governing such regenerative growth may in time result in functionally effective rege eration in mammals, even in humans. The subcommittee concluded that the following areas of research had the best chance for success.

Axonal and dendritic elongation

This research is aimed at studying the behavior of the growing axon (nerve fiber) and the agents that facilitate outgrowth.

Collateral sprouting

After an axon is severed and the portion at the level of the injury degenerates, axons from intact nerve cells grow sideways and reestablish functioning nerve fibers. Studies have shown that some axons of the central nervous system are capable of collateral sprouting and growth following transection. The significance of collateral sprouting as related to the recovery of function remains questionable. Investigators at Ohio State University Medical School considered collateral sprouting to be useless for recovery of function.

Intraaxonal transport

Research has shown that the cell body synthesizes protein and that the protein can be rapidly transported down the length of the axon to the point of the trauma. The protein is used for transmitting nerve impulses and for sustained axonal growth. Protein is also transmitted from the cell endings back to the cell nucleus. Discovery of a dual system of axonal transport is a new development and it established that two-way communication exists within the nerves of the central nervous system.

Properties of neurons with damaged axons

This research involves studying the responses of nerve cells to nerve fiber damage and is important because such damage may cause the death of the cells.

Synaptogenesis

Two cells must make a specific functional contact in order to be effective. The question of how cells recognize their appropriate partners and the mechanisms for recogn[illegible]n that allow for specificity of contacts is vital for the eventual restoration of function.

Biology of neuroglia

Glial cells, collectively known as neuroglia, support cells in the central nervous system, but their biochemical function is unknown. However, researchers do know that without the glial cells the nerve cells die. Neuroglia are deemed important because a type of these cells, the Schwann cell, is present in the peripheral nervous system but is not present in the central nervous system. Researchers speculate that these cells may be the reason the peripheral nervous system can regenerate and the central nervous system cannot.

In addition, when the spinal cord is damaged, the scar tissue that is formed is composed of glial cells. Consequently, further knowledge of the biological processes of these cells may aid in promoting regenerative growth.

Development of biological systems

In relation to the problem of spinal cord regeneration, new biological systems are needed to study the effects of SCI and for cultivating nerve cells. Presently the model for causing traumatic spinal cord injury in an animal is exposure of the cord by a surgical procedure followed by the drop of a weight directly on the exposed cord. However, this is not the way spinal cord injury usually occurs. Some researchers are dissatisfied with this method and are attempting to develop a method for causing traumatic spinal cord injury on a closed system.

A second area in which new systems are required is in the area of cell growth. NIH researchers stated that the medium in which nerve cells are grown may have an effect on the growth. In order to insure scientific accuracy of results, the medium must have no effect on the experiment.

Drug hormone effects

Research is currently underway to discover drugs or hormones which will promote nerve growth and regeneration in the central nervous system. Particular attention has been paid to the protein Nerve Growth Factor. While this protein has had some success in promoting growth of peripheral nerves, the subcommittee reported that its early promise has dimmed and its effects on the central nervous system are inconclusive.

In addition to these eight high priority areas, NINCDS is continuing its program of basic research in the area of the biochemical processes occuring in the central nervous system.

One example of NINCDS supported basic research is work presently underway at Johns Hopkins University Medical School in neuro-embryology. Using a baby chick as the experimental animal, the spinal cord is cut at a point in time prior to the development of its glial cells. The research showed that the nerve fibers will regenerate through the area of the cut because no glial scar tissue forms to block their growth.

A second example is work underway at Cornell University Medical School using a goldfish as the experimental model. Prior research established that the goldfish optic nerve will regenerate when cut. Research is now directed towards determining the cell processes occuring before, during, and after the nerve is cut.

Nerve implant technique

A very promising regeneration project, according to NIH officials, is research supported by the VA called the delayed nerve implant technique. Using the dog as the experimental animal, the spinal cord is crushed with forceps. Tests are then conducted to insure that no nerve impulses were continuing to be transmitted through the spinal cord. After waiting for a period of 1 week for the cord to degenerate, peripheral nerves are transplanted into the gap in the damaged spinal cord. The implanted nerve serves as a conduit or bridge along which the nerve fibers may grown.

Examinations of the treated spinal cords several weeks after the operation established that the nerve fibers had in fact regenerated. Of 10 dogs treated, 4 were able to stand and 2 could also walk. In addition, all the dogs retained some bowel and bladder function.

NIH officials explained that the delayed implant technique is a scientific advance. Previous nerve implants had been done immediagely after injury. The ensuing nerve degeneration created a gap in the cord around the implant and made regeneration unsuccessful. Delaying the implant for 1 week allows the degenerative process to stop. The peripheral nerve tissue can then be attached to each tip of the axon on either side of the gap in the spinal cord and will provide a bridge completely across the gap in the cord. NIH officials suggested that a 1 week delay in performing the technique means that scar tissue has probably not formed. As a result, a barrier to nerve regeneration is removed.

There is some scientific difference of opinion as to whether these regenerated nerve fibers enabled the dogs to walk again or whether the dogs were demonstrating "reflex walking." The apparent walking movements are controlled by the spinal cord and do not involve neural transmissions originating in the brain. Researchers at NIH and the University of Maryland Medical School consider the dog to be a poor choice of an experimental model because of its ability to perform "reflex walking."

According to an NIH scientist, additional research using monkeys as the experimental animal is in the planning stage at NIH. If success is achieved with primates, preliminary experiments are also being planned using paraplegics with minor impairments.

Another problem with this technique is that to date the implanted nerves have been taken either from another leg of the test animal or from the legs of animals in the same litter as the test animal. This is done to prevent rejection of the implant. However, the removal of the sciatic nerve (the nerve used for the implant) leaves the leg paralyzed. The applicability of this technique to man is still in doubt, according to NIH officials. One possibility is to implant nerves from deceased persons. However, little is known about the possibility of rejection or other immunological responses of the human body to an implant from a genetically different person.

REGENERATION RESEARCH IN THE SOVIET UNION

Much attention has been given to advances in regeneration by scientists in the Soviet Union. In order to evaluate regenearation research done by the Soviets, we discussed their techniques and experiments with NIH officials and independent medical authorities and reviewed literature published in the Soviet Union. The following discussion summarizes the opinions of the medical authorities we interviewed on the Soviet research.

In 1973 two scientists, Dr. L.A. Matinian and A.S. Andresian, Orbeli Institute of Physiology, Yerevan, USSR, published a paper entitled "Enzyme Therapy in Organic Lesions of the Spinal Cord" in which they described their experiments with enzymes to inhibit scar formation at the point of damage to the cord of female white rats. They claimed that they could make these rats walk again. In May and June 1976, NINCDS sponsored two meetings to which three Soviet scientists, including Dr. Matinian, were invited to make presentations on their clinical and experimental treatment of spinal cord injury, including enzyme therapy.

Dr. Matinian made a presentation on enzyme research, including a film depicting the results of his work. Enzyme therapy was used on female white rats that were subjected to SCI. In various combinations, four types of enzymes were used--trypsin, elastase, pyrogen, and hyaluronidase. Dr. Matinian and his associates decided to use enzymes to attempt to create favorable conditions for nerve fiber growth in the severed spinal cord by inhibiting scar formation and by promoting regeneration of neurons in the spinal cord.

The female white rats used were 6 to 7 weeks old, of which 348 were subjected to various types of enzyme therapy and 110 were untreated control animals. During the course of the experiment, the cord was exposed and transected. The wound was flushed with saline solution, followed by an administration of enzynme preparation. Various combinations of the enzymes were administered by either flushing into the wound at the time of the operation or by intramuscular injection. Control animals were given the saline solution only. All animals received constant post-operative care.

Evaluation of the effectiveness of the enzyme therapy was measured by comparing responses to stimulation in treated and untreated animals; measuring the amount of electrophysiological stimulation that reached hind limb muscles by brain stimulation and by comparing the experimental and control animals anotomically and with tissue slides. The results of the experiments according to the Soviet studies showed:

--Treated rats lived longer and had less infections than untreated rats.

--Function was restored in a high percentage of the enzyme-treated rats, ranging from a low of 33 percent of those rats treated with hyaluronidase alone to 80 percent of those received trypsin to 92.5 percent of those animals receiving combination therapy. Functional restoration included the return of bladder and motor functions and spontaneous coordinated movements.

--Brain stimulation in the treated animals showed that nerve impulses were transmitted across the site of the transection. This was interpreted to mean that the nerve fibers had bridged the gap between the cut ends of the spinal cord in the enzyme-treated rats and had made the proper functional connections with neurons above and below the transection.

--Tissue slide studies established that the treated rats had a reduction in scar tissue and showed nerve fibers crossing the areas of the transection.

--Regeneration and functional restoration in enzyme-treated rats were maintained throughout their lifetime.

--The treated rats had a very high mortality rate unless constantly attended during the post-operative period.

Thus the Soviets claimed to have solved both the problems of functional recognition and regeneration. Regarding the treatment of human subjects in the Soviet Union, Dr. Matinian and his neurosurgical colleagues stated that enzyme therapy has been used clinically but the results are inconclusive.

Evaluation of the Soviet research

NINCDS officials who attended the meetings with the Soviets were dubious about the significance of their research. According to these officials, the film showing the results of enzyme therapy was very confusing in that it was difficult to know which animals were experimental and which were controls. The officials said that tissue slide sections presented were of poor quality, the histological techniques used were of the pre-World War II variety and chemical tissue analysis was lacking.

In their experiments, NIH researchers have found that two percent of female white rats which suffer complete spinal cord transection will recover and be able to walk without any treatment. As a result, NINCDS officials were skeptical of the interpretation to be drawn from Dr. Matinian's film showing the rats that recovered from SCI after enzyme therapy.

Further criticism was voiced by NIH officials in that the normal scientific progression of using enzymes on larger, more highly developed animals in the experiments had not been done. However, the Soviet experiments with enzyme-treated rats was considered to be worthy of further study by NINCDS officials. In order to evaluate this research, the experiments must be independently duplicated and the results analyzed using modern technology and methodology. NINCDS has awarded a contract to a researcher at the University of Maryland Medical School to duplicate the Soviet experiments. Preliminary results of this research have not supported the contentions of the Soviet scientists regarding regeneration of the spinal cord.

PROSPECTS FOR A BREAKTHROUGH IN SPINAL CORD REGENERATION

Experts in the field of regeneration agreed that chances of a significant, short-term breakthrough are remote. Much basic scientific research remains to be done. Neither of the two main problems in regeneration, regrowing the spinal nerve tracts and providing functional recognition have been solved. The Soviet enzyme experiments, if independently verified, offer hope for the solution of both problems. The delayed nerve implant technique requires additional work but it has shown nerve regeneration is possible and is currently a promising approach in the field, according to medical authorities.

Medical authorities said that the best approach at the present time for solving the problem of paraplegia resulting from acute SCI is to increase the number of acute spinal cord injury centers in the United States while encouraging research to continue on early treatment and regeneration.

COMPUTER BY-PASS APPROACH

In addition to research on spinal cord injuries and regeneration, research has been undertaken that involves bypassing the injured spinal cord by electronic means. Researchers are attempting to use signals generated in the spinal cord, brain, and peripheral nerves and apply them directly to either the peripheral nerves or the spinal cord below the area of the injury. Simultaneous feedback is required wherein sensory nerves feed information through the central nervous system to the brain.

Researchers at the University of Texas Medical School said that in order to successfully achieve a by-pass of an injured spinal cord, signals must be acquired and recorded through electrodes implanted in the nervous system when the brain sends a message to the body through the spinal cord. Signals so acquired must be processed and interpreted by a micro-computer and then reintroduced back into the body in a format that is comprehensible to the body. Basic control mechanisms operating within the nervous system must be mapped and understood in order to provide sensory feedback from the peripheral nervous system through the spinal cord to the brain. None of these areas is without difficulty, according to University of Texas researchers.

The implanted electrode used to acquire signals constitutes a foreign body and generally produces a tissue reaction such as an infection or an immunological response from the body's disease defense system. If implanted directly into the cord, the electrode may become corroded by the spinal fluids.

Signals are acquired from the nervous system in continuous fashion in large numbers. At any one time a vast number of nerve impulses are being transmitted through the nervous system. When a specific movement is desired, a signal is sent down the spinal cord and becomes part of the multitude of other signals carried by the nerve fibers in the cord. The spinal cord acts as a filter which separates the signals and translates them into the desired movement. Researchers at the University of Texas and Rancho Los Amigos Hospital said that at the present state of the art, scientists can neither filter out unwanted signals to isolate the desired signals, nor can they reintroduce the signals back into the nervous system in a language the body can understand. Electronic signals, after processing in a micro-computer, and reintroduced into the nervous sytem, have been so altered that the body does not respond. Researchers at NIH, VA, and the University of Michigan considered the computer by-pass approach to be beyond the level of our present technology.

Ongoing research with a better chance of success, according to medical researchers at Case Western Reserve University, involves an attempt to bypass the central nervous system injury by recording, amplifying, processing, and stimulating at the level of the peripheral nerves. Signals in a healthy portion of the peripheral nervous system are applied directly to either a muscle or a peripheral nerve below the level of the spinal cord injury in an attempt to provide stimulation and restoration of function.

CHAPTER 6

TRAINING AND COORDINATION

The NINCDS National Advisory Council ad hoc Subcommittee on Growth and Regeneration in the Central Nervous System made recommendations to NINCDS in the areas of training and coordination which the Institute has not implemented due either to a shortage of funds or to concern with the appropriateness of the recommendation.

TRAINING

In the field of training, the subcommittee recommended that more emphasis, facilities, and personnel should be directed towards the training of scientists for careers in spinal cord regeneration. An NINCDS official stated that the Institute agreed with this recommendation, but, as previously discussed on page 29, NINCDS has no training program in spinal cord regeneration due to a lack of funds. The $500,000 suggested by an NINCDS official to begin a program could be used to train ten to fifteen post-doctoral trainees a year. This level of funding would provide a reasonable number of spinal cord regeneration specialists, according to the NINCDS official.

To continue progress in the field of spinal cord regeneration, according to medical authoritites, will require investigators to be trained in an institution which affords both clinical and research opportunities. This broad experience would enable researchers to spend their time and effort on problems which, when solved, will lead to improvement in the condition of the spinal cord injured. Acute spinal cord injury centers were suggested by academic researchers and practicing clinicians as the milieu most likely to provide such experience.

COORDINATION EFFORTS

Our review showed that several agencies of the Federal government are involved with the broad problem of spinal cord injury and regeneration with no central direction and each group pursuing its own course in the field. NIH and VA both support research in spinal cord injury, regeneration and electronic prosthesis. The Rehabilitation Services Administration and the National Aeronautics and Space Administration support electrical stimulation research in dealing with spinal cord injury.

The Department of the Navy is supporting nine projects on peripheral nerve regeneration. In fiscal year 1977, these projects cost about $374,000. The National Science Foundation is supporting one project on peripheral nerve regeneration. In fiscal year 1977 the project cost about $35,000. In addition, the Department of the Army supported spinal cord injury and regeneration research from fiscal year 1973 through 1975 at a total cost of about $1.1 milllion. Our work showed that no structured format exists for coordinating the efforts of the various parties involved. Medical authorities at the Federal level said that coordination of efforts results from personal relationships among the concerned parties, membership in peer review groups and attendance at professional meetings.

Regarding the issue of coordinating research efforts in the field of spinal cord injury and regeneration, the subcommittee made three recommendations. It first recommended that a standing advisory committee on central nervous system growth and regeneration be established to monitor research and make policy recommendations to NINCDS. An NINCDS official stated that this recommendation was inappropriate because there already exists an advisory group that performs the functions recommended by the subcommittee. As a result, NINCDS has not acted on this recommendation.

The subcommittee recommended that NINCDS encourage national lay groups with interests in particular neurological diseases to recognize a common objective in promoting research on the central nervous system. An NINCDS official told us that the Institute participates with national lay organizations when invited, but the Institute believes it would be inappropriate for the Federal government to attempt to control lay agencies research efforts.

The final recommendation made by the subcommittee stated that NINCDS should coordinate the exchange of ideas among researchers. An NINCDS official told us that often times a choice must be made as to whether the Institute should sponsor a conference to exchange ideas and coordinate research efforts or to continue awarding meritorious research proposals. NINCDS planned to sponsor an symposium in the spring of 1976 where coordination of research efforts and the status of SCI and regeneration research were to be discussed but the Institute was forced to cancel it due to a lack of funds.