
Current Primary to Tertiary Prevention of Spinal Cord Injury

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Prevention of spinal cord injuries requires a continuum of strategies comprising primary, secondary, and tertiary measures, with the former beginning prior to the injury and the latter continuing for the lifetime of the injured person. Primary prevention is based on detailed epidemiological studies and is facilitated by ongoing registries. Primary prevention involves education, legislation and enforcement, and engineering and technological measures. Secondary injury prevention is the responsibility of the entire health care system and includes first aid, retrieval, and acute hospitalization of the injured person, whereas primary and tertiary injury prevention are the concerns of everyone in the community, both medical and nonmedical personnel. ThinkFirst is a targeted spinal cord injury prevention program that is active in many countries.

Key words: *prevention, spinal cord injury, ThinkFirst*

Spinal cord injury (SCI) occurs at an annual incidence of 11 to 53 cases per million inhabitants in various countries, and the causes vary considerably between countries.¹ In general, motor vehicle crashes account for the largest number of injuries followed by falls, sports and recreation, and violence. In some countries, gunshot wounds have become the most common cause of SCI. Improved injury prevention measures are desperately needed. The types of falls differ greatly among countries, with falls from trees being very common in some underdeveloped countries and falls from buildings or at construction sites taking a large toll in developed countries. Similarly, there are major differences in etiology between urban and rural centers and between pediatric and adult populations.² Unfortunately, there is still no effective treatment to restore neurological function in the majority of patients with major SCI, and thus, these

injuries usually cause lifelong disability. Accordingly, prevention is the only cure, but there is insufficient attention paid to prevention efforts in most countries. In North America, the current costs for acute care, rehabilitation, lifetime care, and lost earnings amount to several million dollars for each person with major SCI; thus, greater efforts at prevention would be highly cost-effective.

This article will discuss all three phases of injury prevention from primary to tertiary but will concentrate on primary prevention efforts.

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Epidemiology of Neurotrauma

To develop effective prevention programs, it is essential to carefully document cases of SCI. In Canada, provinces submit annual data to a National Trauma Registry that grew out of the Ontario Trauma Registry. The trauma registry collects information from hospitals' admission lists and from coroners' offices. Until recently, there was no data collection from emergency departments for patients who were not admitted. However, virtually all patients with SCI are admitted and are therefore captured by the current system. The National Trauma Registry reported that there were 1,347 SCI admissions to Canadian hospitals from 1998 to 1999.³ These injuries represented about 1% of injury admissions; the leading causes were motor vehicle crashes in 43% and unintentional falls in 36%. The Canadian registry still has significant shortcomings, such as its inability to define accurately the exact circumstances of injury in the falls group. In some countries such as Australia, maintenance of a separate SCI registry has been very successful.⁴

Types or Phases of Prevention of SCI

It is useful to categorize SCI prevention efforts as primary, secondary, or tertiary based on the timing of the intervention in relation to the occurrence of SCI. Primary prevention comprises the efforts to prevent SCI. Examples of primary prevention with respect to motor vehicle crashes are seatbelts, airbags, driver education, introduction of rules such as speed limits, and enforcement of rules. In sports and recreation, primary prevention includes the recently introduced rule of "no checking from

behind" in ice hockey and the rules against spearing as an offensive or defensive maneuver in football in the United States.

Secondary prevention begins immediately after the occurrence of SCI and involves prevention of worsening of the neurological deficit and prevention of all the secondary sequelae of major trauma that can lead to further morbidity and even mortality. Examples of secondary prevention measures in persons with SCI include informed, high-quality first aid with prevention of movement of unstable fractures, the use of a cervical collar, administration of neuroprotective drugs, and maintenance of normotension to ensure adequate blood flow to the injured spinal cord.

Tertiary prevention begins immediately after the acute phase of care and involves prevention of long-term disability. Examples of tertiary prevention are measures to prevent deep venous thrombosis and pulmonary embolism, early mobilization of patients, and the use of intermittent catheterization for treatment of the neurogenic bladder to prevent long-term urinary tract infections. It is useful to think of primary, secondary, and tertiary prevention as a continuum beginning well before the time of injury and continuing without interruption throughout the life of the person with SCI.

Haddon Matrix Concept Applied to SCI Prevention in Motor Vehicle Crashes

Haddon was an engineer who reported in 1968 the concept of analyzing trauma according to the etiology identified in all three phases of injury: preinjury, injury, and postinjury.⁵ This model is well suited to injury prevention: primary prevention measures are applied during the preinjury phase,

Table 1. Haddon matrix concept applied to the prevention of spinal cord injury in motor vehicle crashes

	Primary prevention (precrash)	Secondary prevention (crash)	Tertiary prevention (postcrash)
Driver	Classroom education Driving school Test drives Licensing	Extrication techniques	No return to driving until fully recovered
Motor vehicle	Brake tests Running lights Child seats Tires	Seat belts Air bags Head rests Helmets	Don't use until repaired
Road	Establish rules Stop lights Crosswalks	Shoulders Guard rails Barriers Divided highways	Debris removal Police Involvement
Community	Safety programs Rules/laws First aid instruction	First aid system Ambulances	Hospital system Data collection SCI registry

secondary prevention measures are applied beginning at the time of the injury, and tertiary measures are applied postinjury. With respect to motor vehicle crashes, in each phase of injury there are prevention measures that relate to the driver, the motor vehicle, the road, and the community, as shown in **Table 1**. If one considers the driver, the measures that would be taken to prevent the injury would include education of that driver in elementary or secondary school or in a driving school. Also, test drives with a driving instructor and the entire licensing process would be designed to prevent SCI prior to the crash. At the time of the crash, the prevention measures relating to the driver would include careful extrication utilizing an

extraction device to prevent further injury. Indeed, there are highly effective, specific spinal immobilization devices that immobilize the head and neck to prevent any movement of an unstable fracture and possible worsening of the neurological deficit. In the tertiary prevention stage, measures directed toward the driver after the crash include prevention of the injured driver from returning to driving until he or she has fully recovered from the acute effects and, if still disabled, until he or she has had disability assessment and provision of any necessary aids or vehicle modification. Persons who have their neck immobilized in a firm collar should not return to driving.

The local community and the nation

should have prevention programs in place in the precrash, crash, and postcrash phases. For example, local communities should organize their first aid systems so that there is early judicious retrieval of SCI victims followed by transport to an appropriate center for acute management of SCI that has the necessary diagnostic and treatment equipment and personnel and then transfer to an appropriately equipped and staffed rehabilitation center, as required. It is the community's responsibility to have an organized system of data collection of SCI statistics, preferably within the context of an overall, comprehensive, and continuing trauma registry. Comprehensive tracking of the epidemiology of SCI is an essential component of tertiary injury prevention. Although costly, national trauma registries are essential to combat the trauma epidemic.

Who Is Involved in the Prevention of SCI?

With respect to primary prevention, individuals, local communities, and nations are all involved. Governments and nongovernmental organizations, such as ThinkFirst, are also involved. ThinkFirst directs most of its attention toward prevention of brain injuries and SCIs; these represent about half the injuries that cause major lifelong disability and mortality. Indeed, with respect to mortality and lifelong disability, brain and spinal cord injury rank so high that it is logical and appropriate to have a specific injury prevention program that is focused on these injuries. For example, Kraus found that 57% of all high acuity trauma patients have some neurologic injury and that half of the 150,000 injury-related deaths that occur annually in the United States involve a serious brain

injury that is primarily responsible for the patient's demise.⁶ Also, with the possible exceptions of drowning and poisoning, all types of trauma have almost identical causes, and thus prevention efforts focused on brain and spinal cord injury will be effective for almost all types of injuries.

In contrast, secondary prevention of SCI is the responsibility of health care professionals, especially first aid personnel, neurosurgeons, orthopedic surgeons, and neuroscience nurses. In tertiary prevention, physical medicine and rehabilitation specialists, family doctors, rehabilitation nurses, and therapists are especially involved.

Timing, Location, and Relative Importance of the Three Phases of Injury Prevention

Primary prevention efforts must be in force at all times and continuously throughout the life of an individual. It is the responsibility of the individual, the community, and country to ensure that its citizens are educated about risk-taking behavior and its consequences with respect to SCI. This requires the continual updating of injury prevention programs as society invents new risk-taking activities. The need for continual change in prevention programs is especially evident in the sports and recreation field in developed countries where many new high-risk activities are invented; are glorified by the media, especially television; and attract young people to attempt activities beyond their skills and without due caution. Secondary prevention begins immediately after an injury occurs and lasts for the entire acute phase, which usually extends for weeks to months. Tertiary prevention begins during the early rehabilita-

tion phase and should continue for the lifetime of the injured person.

With respect to the location of injury prevention programs, primary prevention is ubiquitous in location. For example, with motor vehicle crashes (**Table 1**), prevention education should be practiced on the streets, in the classroom, and in the community at large at all sites that SCI occurs. In contrast, secondary prevention occurs at the scene of the injury, and then continues during the hospitalization phase within the health care institutions. The location for tertiary prevention efforts is also ubiquitous.

All phases of injury prevention are of equal importance for preservation of life, prevention of death, and reduction of the morbidity and complications of SCI. Indeed, primary, secondary, and tertiary prevention are all a matter of life and death and thus are all extremely important for the individual and for society.

ThinkFirst Injury Prevention Programs

ThinkFirst began in the United States in 1986, in Canada in 1992, and in Mexico in 2001. Programs have also begun in Singapore, the West Indies, Australia, Lebanon, and South Korea. In Canada, ThinkFirst is a bilingual program with the French program titled “Penser d’Abord Canada.” In each country, ThinkFirst is recognized and endorsed by the relevant professional organizations of physicians and surgeons. In Canada, ThinkFirst is endorsed by the Canadian Congress of Neurological Sciences that comprises all of Canada’s neurologists and neurosurgeons, the Canadian Association of Neurosciences Nurses, and the Canadian Spine Society. This endorsement allows input of practitioners into the injury prevention

program for education purposes, fundraising, and medical expertise. The mission statement for the ThinkFirst Foundation of Canada indicates that ThinkFirst is “dedicated to the prevention of brain and spinal cord injury through education aimed at promoting healthy behavior in children and youth.” ThinkFirst’s motto is that it teaches young people to “use their brains to protect their bodies,” and thus it concentrates on primary injury prevention. Although ThinkFirst targets children and youth, several of its programs are also directed toward adults, such as those targeted toward reduction of SCI in sports and recreation.

Three Injury Prevention Strategies

There are three main strategies utilized by ThinkFirst and other injury prevention programs, the first of which is the combination of enforcing existing safety rules and developing new legislative initiatives to enact new rules. Bicycle helmet legislation is a good example. In the province of Ontario, Canada, bicycle helmet legislation was passed in 1995, but it only required bicyclists less than 18 years of age to wear helmets. In some provinces of Canada, legislation requires bicyclists of all ages to wear helmets, whereas in other provinces there is no bicycle helmet legislation at all. This is highly reprehensible. Furthermore, when legislation was first introduced in Ontario, the compliance rate was very high because of active enforcement by the police, but enforcement dwindled and the compliance rate dropped considerably. Thus, both appropriate legislation and consistent enforcement are required for effective injury prevention. Although helmets are designed to protect the brain and do not protect the spine, it is highly likely that

the safety message borne by campaigns to protect the brain through helmet usage will increase caution among riders. Since bicycling causes a significant number of SCIs, these helmet campaigns may also reduce the number of SCIs.

The second major strategy for injury prevention is the combination of engineering advances and technological interventions. With respect to SCI, we have progressed markedly in terms of the design and use of seatbelts, airbags, and children's and infants' seats. In other respects, engineering and technological interventions have failed to prevent large numbers of motor vehicle crashes due to improperly designed crosswalks, rollovers in SUVs, and poor highway construction.

Education is the third major category of prevention strategy, and education is ThinkFirst's major activity. The educational interventions utilize a variety of venues, with specific programs for schools and others for the community at large.

School-based programs

ThinkFirst has two major school-based programs: TD ThinkFirst for Kids for elementary schools, ranging from kindergarten to grade 8, and ThinkFirst for Teens that is targeted toward all high school grades beginning with grade 7 or 8. TD ThinkFirst for Kids is a comprehensive brain and SCI prevention program delivered by elementary school teachers based on four separate curriculums: (a) the Wonderers for kindergarten; (b) the Discoverers for grades 1, 2, and 3; (c) the Explorers for grades 4, 5, and 6; and (d) the Navigators for grades 7 and 8.

The three kindergarten-to-grade-6 curricula encompass six main areas:

1. "Using my brain and spinal cord" –

students are given grade-specific knowledge of the anatomy and physiology of the brain and spinal cord to give them an appreciation of the function and fragility of these organs

2. Pedestrian and vehicular safety
3. Cycling safety
4. Safety in sports and recreation
5. Solving problems and safety around dangerous objects
6. Avoiding the hazards of choking, suffocation, and strangulation

The grades 7 and 8 curriculum provides a more advanced understanding of neuroanatomy and physiology and includes discussions on decision-making and risk-taking behavior. All curricula include attention to violence and problem solving and discussion of playgrounds, recreational activities, and sports.

These curricula were developed by teachers and endorsed by school boards and are based on current applied learning and behavioral theories. ThinkFirst Canada assembled a team of health and education professionals to "Canadianize" the grades 1 to 3 curriculum initially developed by the ThinkFirst Foundation of the United States with a grant from the Johnson & Johnson Corporation. ThinkFirst Canada created the new curricula for grades 4 to 8 and for kindergarten. The Canadian curricula were designed to meet all requirements of the provincial Ministries of Education. The supporting materials for each curriculum include exercise sheets for the students to complete, full-color classroom posters, comic strips for the younger children, an animated video, and additional resources such as anatomical descriptions of the brain and spinal cord. There are also letters to the parents to be taken home by the students and suggested follow-up home ac-

tivities. ThinkFirst Chapters are responsible for distributing the curricula to the elementary schools and providing in-service presentations to teachers to instruct them on the use of these curricula and to engage their cooperation. Teachers are told that they are instrumental in educating the children as to why their first choice must be to “think first” in order to live full productive and injury-free lives. The goal is to make teachers understand that prevention is a learned behavior.

Evaluations of the ThinkFirst for Kids program have shown that it is effective in improving knowledge of injury mechanisms and that grades 1, 2, and 3 children had improved self-reported behaviors after being given the program.^{7,8} Also, there is a prospective, randomized, controlled longitudinal study underway in Ontario to evaluate the effectiveness of the program in reducing the incidence of injury in treatment schools that received the program compared with control schools that did not receive the program.

ThinkFirst for Teens is targeted toward high school students. In contrast to ThinkFirst for Kids, it is presented by a health care professional such as a physician, nurse, or therapist and also by an injured person known as a voice of injury prevention (VIP) speaker. The ThinkFirst for Teens presentation is given to high school classes or to assemblies. The program begins with a “hard-hitting” video that shows simulated or actual crash scenes including victims being extricated and transported to emergency rooms. The video provides profiles of injured persons and shows the profound effects of SCI on their lives. The ThinkFirst for Teens program contains neuroanatomy and physiology information to show the importance and fragility of the brain and spinal cord. The program lasts 1 hour and ends with a ques-

tion-and-answer period during which students are encouraged to question the VIP speaker about “life in a wheelchair.” The effectiveness of this program was evaluated by Wesner⁹ who showed that it increased knowledge of injury mechanisms and prevention strategies among grade 6 and 7 youths.

There are several variations on this high school program, one of which is the Party Program (Prevention of Alcohol-Related Trauma in Youth) that began in Canada and brings teenagers to a trauma hospital for a first-hand view of the emergency department, operating rooms, intensive care unit, and wards. The program is conducted by trauma personnel, usually trauma nurses, and also utilizes VIP speakers. One new approach to teenagers that is being developed is a combination of ThinkFirst and Party called ThinkFirst Party Later that comprises an initial school-based injury prevention presentation followed by a hospital visit with emphasis on trauma.

Community-based targeted SCI prevention programs

ThinkFirst and other organizations have used a variety of methods to deliver SCI prevention programs to the community at large. One very effective method is the use of public service announcements (PSAs) on television. One of our first PSAs showed a diver who lost function below the level of his SCI; the injured person was represented by a series of TV sets that lost their power. A recently developed PSA showed an unhelmeted skateboarder who crashed and emphasized the importance of wearing a helmet.

ThinkFirst Canada has also developed targeted injury prevention programs for spe-

cific sports and recreational activities. Diving is still the most common cause of SCI in sports and recreation, and this has led to the development of two programs for prevention of diving-related SCI. The first is Dive Right, which is a video targeted to children up to grade 4, and the second is Sudden Impact, a video targeted to grades 5 and higher that features the injuries sustained by several young people who broke their necks at pools or beaches.

Due to the major increase in SCI in hockey in Canada and other countries during the 1970s and 1980s, two targeted injury prevention programs in ice hockey were created by ThinkFirst Canada. The first was Smart Hockey with Mike Bossy developed in 1988, and the second was Smart Hockey: More Safety More Fun developed in 2001–2002. These programs consist of a video and accompanying booklet warning against specific injurious behaviors in ice hockey that have been documented to lead to SCI, especially pushing or checking from behind into the boards.¹⁰ The hockey injury prevention project comprised a number of other strategies including education of players, parents, coaches, referees, leagues, trainers, and physicians about the identified mechanisms of injury. Breakaway goal posts reduce impact force and were made mandatory in many leagues. Education involved writing and distributing booklets, providing coaching clinics, and conducting presentations at meetings of trainers. Enlisting the cooperation of professional players and professional leagues was difficult because of their reluctance to acknowledge the existence of injury due to the potential negative effects on attendance. Nevertheless, many professional athletes volunteered to help with injury prevention measures. A second strategy was the introduction of new rules and rules enforcement; this required the cooperation of

leagues and the ongoing enforcement of the rules by leagues and their referees. Evidence of the damaging effects of checking or pushing from behind led to the adoption of specific rules against these actions. As a result of these and other injury prevention measures, there has been a decline in the incidence of major SCI in ice hockey.¹¹ However, there is still a need for further research in injury prevention in hockey such as determining ways to improve the shock absorption of helmets and the boards around hockey rinks.

In the United States, football was one of the sports in which SCI occurred most frequently. In the 1970s, it was recognized that the use of the head as an offensive or defensive weapon (spearing) and certain defensive maneuvers such as “clotheslining” were causing cervical SCI in football. After specific rules changes and new coaching strategies were developed to prevent these injuries, there was a decline in the incidence of SCI in football.¹²

ThinkFirst is currently developing additional targeted injury prevention programs for other sports and recreational activities where SCI or brain injury are frequent, including equestrian activities, soccer, alpine skiing, and snowboarding.

As noted earlier, in some countries gunshot wounds are a very common cause of SCI, and improved injury prevention measures are desperately needed. A number of measures are being tried in various countries that include legislation for childproof safety locks in the United States and a gun registry that has been introduced in Canada.

Secondary Injury Prevention

There has been a major improvement in our knowledge of the pathophysiology of acute SCI, and there is general agreement

Primary and Secondary Mechanisms of Acute Spinal Cord Injury

- A. Primary injury mechanisms
 1. Acute compression
 2. Impact
 3. Missile
 4. Distraction
 5. Laceration
 6. Shear

- B. Secondary injury mechanisms
 1. Vascular changes
 - (a) *Systemic effects* including neurogenic shock leading to spinal cord ischemia; prolonged hypotension and decreased cardiac output with increase circulating catecholamines
 - (b) *Local vascular damage* of the spinal cord microcirculation leading to spinal cord ischemia; mechanical disruption of capillaries and venules; hemorrhage, especially into grey matter; loss of microcirculation—mechanical, thrombosis, vasospasm; reduction of spinal cord blood flow – thrombosis, vasospasm, loss of autoregulation
 2. Electrolyte shifts
 - (a) increased intracellular calcium
 - (b) increased extracellular potassium
 - (c) increased intracellular sodium
 3. Edema
 4. Loss of energy metabolism, decreased ATP production
 5. Apoptosis – cell death, loss of trophic factor support
 6. Biochemical changes leading to necrosis
 - (a) Excitotoxicity-glutamate accumulation
 - (b) Neurotransmitter accumulation – e.g., catecholamines– noradrenaline, dopamine, serotonin
 - (c) acid release
 - (d) free radical production
 - (e) eicosanoid production (prostaglandins)
 - (f) lipid peroxidation
 - (g) endogenous opioids
 - (h) cytokines
 - (i) nitric oxide

that after acute SCI there is a series of secondary mechanisms of injury with the potential to cause further damage to the spinal cord.¹³ The primary injury mechanisms include

acute compression by in-driven bone fragments or disc; dislocation of vertebra; or distraction, laceration, contusion, or whip-lash. The secondary injury mechanisms in-

clude vascular injuries; electrolyte changes; production of free radicals; lipid peroxidation; other biochemical changes; edema formation; loss of energy metabolism; eicosanoid production, including prostaglandins; endogenous opioids; cytokines; nitric oxide; excitotoxicity due to glutamate neurotransmitter accumulation; and apoptosis (see box titled, "Primary and Secondary Mechanisms of Acute Spinal Cord Injury"). It has become evident from experimental and clinical studies of SCI that there is a critical window of opportunity for prevention of these secondary mechanisms of injury. For some measures, such as the restoration of spinal cord blood flow and prevention of posttraumatic ischemia, the critical time for action may be within 8 hours of injury; for other mechanisms, such as the prevention of apoptosis, the therapeutic window may extend much longer. Neuroprotective agents such as steroids were shown experimentally to counteract many of these processes including reduction of blood flow, edema formation, electrolyte imbalance, and formation of free radicals. Although they are still used in many SCI centers, there is controversy about the effectiveness of steroids and concern about the side effects of the large doses that have been required to produce even a small clinical improvement.^{14,15}

It has been established that once SCI has occurred there are many effective measures for preventing further loss of function due to additional damage of spinal cord tissue. Best treatment regimens have been postulated (see boxes titled, "Methods of Secondary Injury Prevention" and "'Best Treatment' of Acute Spinal Cord Injury") on so-called evidence-based principles. For SCI, many of these measures have been described in the recently published "Guidelines for the Man-

Methods of Secondary Injury Prevention

1. Strict attention to the ABCs of trauma management – airway, breathing, and circulation.
2. No injudicious movement of the spine, and immobilization of the whole spine.
3. Ensure homeostasis with respect to normotension, prevention of fever, etc.
4. Early transfer to an appropriate facility with trained personnel and required equipment.
5. Major spinal cord injury, especially in the cervical region, should be managed initially in an intensive care unit.
6. Early complete imaging of the spine by CT and the spinal cord by MRI.
7. Holistic treatment – treat the whole patient including all systems.
8. Perform surgical decompression of the spinal cord in selected cases, and do it as early as possible.
9. Rehabilitation begins in the first hour after injury.

agement of Acute Cervical Spine and Spinal Cord Injuries."¹⁶ Although this document has many shortcomings that require revision, there is much that is useful.

The attention to the principles of the ABCs of trauma management, establishment and maintenance of an adequate airway, maintenance of adequate breathing, and support of the circulation, is of critical importance to SCI. The traumatized spinal cord is acutely sensitive to further deprivation of oxygen or blood flow; thus the ABCs of trauma man-

“Best Treatment” of Acute Spinal Cord Injury

First hour

ABCs of trauma management
 Immobilization of spine
 Restore any hypotension to normotension
 Consider giving neuroprotective agents (methylprednisolone)
 Treat in appropriate facility and in intensive care unit

Later

Treat the whole patient – rehabilitation begins almost immediately
 Relieve persisting compression of the spinal cord in selected patients, and do it as early as possible
 Achieve spinal stability
 Mobilize patient early
 Actively avoid complications

agement are extremely important for management of the person with SCI. The treatment of neurogenic shock in SCI has been extensively discussed,¹⁷ and most authorities agree that restoration of normotension provides the best milieu for recovery of damaged tissue.¹⁸

From initial first aid management and at every treatment step thereafter, it is essential to restrict motion of the injured spinal column. Prevention of injudicious movement can be accomplished by immobilization of the spine with various emergency retrieval strategies and devices, as noted previously. Prevention of fever and hypotension and general maintenance of homeostasis are stressed. It is generally recognized that not every hospital should be

treating acute SCI and that early transfer to an appropriate facility with trained staff and adequate equipment for imaging and emergency surgery are essential for proper care.¹⁹ Critical care management of SCI requires continuing management of airway, breathing, and circulation; careful neurologic observation for neurological deterioration; attention to the GI tract, bladder, skin, nutrition, and psychology; prophylaxis against deep venous thrombosis and pulmonary embolism; and management of pain.²⁰ Invasive monitoring is required in an intensive care setting for most major cervical cord injuries; this implies a central venous line to measure central venous pressure and a pulmonary artery catheter to maintain pulmonary capillary wedge pressure of 18 mm Hg. The aim is to maintain systolic pressure of 80 to 100 mm Hg and urine output of 0.5 mL/kg/h and to prevent overhydration and pulmonary edema.¹⁸ One of the major benefits of the improved knowledge of the pathophysiology of acute SCI is the opportunity to prevent worsening of posttraumatic ischemia of the spinal cord. The prevention measures include maintenance of normotension by administration of fluids and vasopressors as needed. This requires careful monitoring in an intensive care unit, and in most cases invasive monitoring is necessary.

Early complete imaging of the spine and spinal cord are essential for detection of indriven bone fragments or disc and for decision-making about surgical decompression of the spinal cord. It is still not known if early surgical decompression produces improved recovery.²¹ It is generally acknowledged that adequate imaging implies early use of magnetic resonance imaging to visualize the spinal cord and early use of computerized to-

mography to image the spinal column in every case, ideally within the first 2 hours of injury. Finally, comprehensive secondary injury prevention involves treatment of the whole patient so that every system is continually scrutinized, including the skin, and the gastrointestinal and urinary tracts are monitored from the first hour. There is general agreement that rehabilitation begins in the first hour after injury.

Tertiary Injury Prevention

Tertiary injury prevention for patients with SCI begins after the acute hospitalization phase ends and the patient is either transferred home or to a rehabilitation setting. A series of measures designed to prevent all of the medical complications of acute SCI begins at that time. This phase of prevention is noted in this article for completeness only, because it is the main topic of another article in this issue (Potter et al., "Challenges in Educating Individuals with SCI to Reduce Secondary Conditions"). Essentially, the measures are based on the holistic principle of "treating the whole patient"; this includes treating all systems. The main areas of tertiary injury prevention include the prevention of deep venous thrombosis, pulmonary embolism, pressure sores, urosepsis, and contractures. Active muscle exercises are used for the prevention of venous thrombosis and limb contractures. Recent scientific evidence has found that these exercises induce the production of neurotrophic factors that in turn promote survival and regeneration of neurons and glia.²² Also, the newer forms of rehabilitation that include gravity-assisted gait training^{23,24} can be considered to facilitate the prevention of complications as well as to promote recovery of the injured nervous system.

Evaluation of the Effectiveness of Injury Prevention Programs

It is imperative to evaluate the effectiveness of any program designed for primary, secondary, or tertiary prevention of SCI. There should be evaluations of the process of the intervention, the effects on knowledge and behavior, and most important the effects of the intervention on the incidence of SCI. ThinkFirst has conducted several evaluations of its school-based programs.⁷⁻⁹ One evaluation of our Sudden Impact program to prevent SCI due to shallow water diving showed a flawed process with respect to distribution of the materials destined for classroom use in high schools. Many of the targeted schools failed to receive the program, and others that did receive it failed to show it to the students.²⁵ Evaluation of the Smart Hockey program has taken many forms including evaluation of knowledge and behavior²⁶ and evaluation of SCI incidence,¹¹ both of which indicated that the interventions were effective.

Conclusion

Prevention in SCI is a continuum of activities comprising primary, secondary, and tertiary measures, with the former beginning prior to the injury and the latter continuing for the lifetime of the injured person. The primary phase to prevent SCI from occurring requires a multifactorial approach involving education, legislation, enforcement, and engineering and technological measures. SCI prevention in the primary phase must be the concern of everyone in the community. It is both very costly and cost-effective. Detailed, comprehensive, and continuing epidemiological studies and

registries are very costly, but they are very cost-effective in terms of reduction of the incidence of injury. There are excellent examples of reduction of SCI incidence in specific sports after targeted, injury prevention programs are presented. Secondary injury prevention in SCI is the responsibility of the entire health care system and includes first aid, retrieval, and acute hospitalization, whereas primary and tertiary injury prevention are the concerns of everyone in the local and national community, including medical and nonmedical personnel. Pathophysiological studies of acute SCI indicate that there are major opportunities for preventing the worsening of neurological function and for supporting recovery mechanisms by adequate

attention to early homeostasis and holistic patient management.

ThinkFirst is a targeted SCI and brain injury prevention program that is active in several countries; it has made significant contributions to the prevention of SCI through its school-based and community-based programs designed to educate the public about SCI.

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