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TOPIC PAPER

Epidemiology and pathophysiology of neurogenic bladder after spinal cord injury

Rizwan Hamid[1,2] · Marcio Augusto Averbeck[3] · Humberto Chiang[4] · Arturo Garcia[5] · Riyad T. Al Mousa[6] · Seung-June Oh[7] · Anita Patel[8,9] · Mauricio Plata[10] · Giulio Del Popolo[11]

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Abstract
Spinal cord injury (SCI) usually affects younger age groups with male preponderance. The most common traumatic cause is road traffic accident followed by sports accidents and gun-shot injuries. Infections and vascular events make up non-traumatic causes. There is regional variance in incidence and prevalence of SCI. Most systematic reviews have been undertaken from USA, Canada, and Australia with only few from Asia with resultant difficulty in estimation of worldwide figures. Overall, the incidence varies from 12 to more than 65 cases/million per year. The first peak is in young men between 15 and 29 years and second peak in older adults. The average age at injury is 40 years, with commonest injury being incomplete tetraplegia followed by complete paraplegia, complete tetraplegia, and incomplete paraplegia. The bladder function is reliant on both central and peripheral nervous systems for co-ordination of storage and voiding phases. The pathophysiology of bladder dysfunction can be described as an alteration in micturition reflex. It is postulated that a new spinal reflex circuit develops which is mediated by C fibers as response to reorganization of synaptic connections in spinal cord. This is responsible for the development of neurogenic detrusor overactivity (NDO). Various neurotrophic hormones like nerve growth factor affect the morphological and physiological changes of the bladder afferent neurons leading to neuropathic bladder dysfunction. A suprasacral SCI usually results in a voiding pattern consistent with NDO and sphincter dyssynergia. Injury to either the sacral cord or cauda equina results in detrusor hypoactivity/areflexia with sphincter weakness.

Keywords Spinal cord injury · Traumatic · Non-traumatic · Tetraplegia · Paraplegia · Variance across developed and developing world · Neurogenic detrusor overactivity · Detrusor sphincter dyssynergia · Detrusor underactivity · Sphincter weakness · C fiber activity · Neurotropic factors · Epidemiology · Pathophysiology

Introduction

Spinal cord injury (SCI) is a devastating incident. It can result from traumatic or non-traumatic events leading to fracture or dislocation of spinal column resulting in damage to the spinal cord. The major traumatic causes include a vehicular or diving accident, falls, gun-shot injuries, disc prolapse, sudden hyperextension injury with infections, and vascular events generally making up the non-traumatic causes.

The degree of neurological damage and consequent deficit depends on the level, severity, and extent of injury and if

✉ Rizwan Hamid
hamid_rizwan@hotmail.com

1 London Spinal Injuries Unit, London, UK

2 University College London Hospitals, London, UK

3 Moinhos de Vento Hospital, Porto Alegre, Brazil

4 Clinica Las Condes, Santiago, Chile

5 Hospital Medica Sur, Mexico, Mexico

6 King Fahad Specialist Hospital, Dammam, Saudi Arabia

7 Department of Urology, Seoul National University College of Medicine, Seoul National University Hospital, Seoul, Republic of Korea

8 Global Hospital, Mumbai, India

9 Muljibhai Patel Urology Hospital, Nadiad, Gujarat, India

10 Department of Urology, University of los Andes Fundacion Santa Fé de Bogotá University Hospital, Bogota, Colombia

11 Neuro-Urology and Spinal Unit, Careggi University Hospital, Florence, Italy

the cord transection is complete or partial. Pelvic floor dysfunction including genitourinary dysfunction is a frequent sequelae of SCI and can have a significant negative impact on both the amount and quality of life in these patients. The urological management of such patients involves protection of the upper tracts, prevention of complications, facilitating drainage of bladder and maintaining the quality of life [1].

Epidemiology of SCI

There is a significant regional variation in the incidence and prevalence of SCI. Not surprisingly, most systematic reviews for this condition have been undertaken from developed world including USA, Canada, and Australia with only a few from underdeveloped world. As a result, it is difficult to estimate the exact figures worldwide.

SCI can be due to traumatic or non-traumatic etiology, as defined by international spinal cord society (ISCOS) [2]. However, there is not a complete consensus to define some causes, such as iatrogenic lesion, as either traumatic or non-traumatic. This leads to considerable difficulty in properly assessing the epidemiology of SCI and the impact of risk factors in etiologic processes. Moreover, an accurate quantification of the worldwide prevalence and incidence of SCI is challenging and not entirely representative due to the lack of standardized methods of assessment across regions, limited information in the data collected and paucity of reliable data from developing countries and rural areas.

There are significant differences as to the causes of SCI between countries, and among regions within a country depending upon urban or rural locations. Overall, the incidence reported varies from 12 to more than 65 cases/million per year. Olmsted county data from 1975 to 1981 suggested an age- and sex-adjusted incidence rate of 71 injuries/million [3]. More recent data showed that the incidence of SCI, excluding those who die at the scene, is 3.5–4.0/100,000 persons annually in the USA [4, 5] According to studies considered to be most accurate, the annual incidence of SCI reported in a national system for the year 1991 was around 30.0 and 32.1 persons/million population in the USA. These rates correspond to between 7,500 and 8,000 new cases each year at that time [6]. Recent data from 2016 show that with a population size of 314 million people in the USA, the estimated annual incidence of SCI is approximately 54 cases/million population or approximately 17,000 new SCI cases each year [7]. The annual incidence (per million persons) varies widely by country: from 27 in Japan [8], to 13.4 in Switzerland [9] 12.7 in France [10] and 16.7 in South Africa [11]. The annual incidence varies within Europe with 12.1 cases/million in The Netherlands compared to 57.8 Portugal [12] [13]. The reported incidence from other countries shows a similar trend with 38 cases/million including traumatic and non-traumatic SCI in Saudi Arabia between 2000 and 2010 [14].

Van den Berg demonstrated in a systematic review that a threefold variation in incidence rates between developed countries, with highest rates reported in Canada and Portugal. Most traumatic spinal cord injury (tSCI) studies show a bimodal age distribution. The first peak was found in young men between 15 and 29 years and a second peak in older adults (mostly > or = 65 years and females) [15]. Cripps et al. reported in 2011 a prevalence ranging from 236 to 1009/million, but noted that prevalence data are extremely scarce, especially from Asian, African, and South-American countries. The same review found that North America (39/million) and Japan (40.2/million) had more than twice the incidence of Australia (15/million) and Western Europe (16/million) [16]. Fitzharris [17] used a population-based regression model and estimated the overall incidence rate to be 27.5 traumatic SCI per million persons in the global population (population for 131 countries: 6.250 billion). The estimated tSCI incidence rate ranged from 18.3 to 42.9/million [17].

The USA maintains a National Spinal Cord Injury Statistical Centre at Birmingham, Alabama [7]. This reported approximately 12,000 new cases each year with 4:1 as the male-to-female ratio. The average age at injury was 40 years, with commonest injury being incomplete tetraplegia at 30%, followed by 25.6% for complete paraplegia, 20.4% complete tetraplegia, and 18.5% incomplete paraplegia. In the past, the leading cause of death amongst SCI patients was renal failure; however, improved urological management has changed this picture. Presently, pneumonia, pulmonary emboli, and septicemia supersede renal failure as the cause of death.

Traumatic SCI

The highest prevalence of tSCI has been noted in USA in a recent review by Singh et al. [18] at 906/million and lowest in Rhone-Alps region, France at 250/million. The crude annual incidence in USA was highest in Alaska (83/million) and lowest in Alabama (29.4/million). The incidence in other parts of the world was 58/million in Central Portugal, 19.5/million in Stockholm, Sweden, 16.9/million in Southeast Turkey, 14.6/million in Taipei, Taiwan, and lowest at 12.7/million at Rhone-alps, France. Road traffic accidents remain the single most common factor followed closely by falls; this is especially true in the elderly population. The United Arab Emirates reported the highest incidence of SCI due to work related fall injuries, mainly involving immigrant Indian population [19].

Non-traumatic SCI

The epidemiology of ntSCI reveals somewhat different statistics about cause, incidence, and prevalence [20] in contrast to tSCI. The reported prevalence rate is 2,310/million in India and 1,120/million in Canada. Not surprisingly, in the developing countries, there was a higher proportion of infective causes (tuberculous and HIV), while the developed countries had a higher proportion of degenerative and neoplastic etiologies. The annual incidence of non-traumatic SCI in various regions of the world according to WHO is 20/million in high-income Asia Pacific; 26/million in Australasia; 6/million in Western Europe and 76/million in high-income parts of North America. Unfortunately, the corresponding figures are not available from the developing countries due to lack of adequate data collection. Non-adherence to minimum standards of data collection along with a piecemeal approach to data collection was cited as the main causes for poor epidemiological information in this study.

SCI and pediatric population

The estimated incidence of spinal injuries in pediatric population was 24/million, with higher incidence of severe injuries amongst black adolescents [21]. Fortunately, the overall incidence of motor vehicular accidents leading to SCI seems to be coming down, primarily due to increased motor vehicular safety and improved traffic regulations [22].

Conclusions

1. The USA has the highest incidence of tSCI with figures ranging from 83/million in Alaska to 29.4/million in Alabama.
2. Overall incidence and prevalence figures of tSCI show wide regional variation.
3. The most common cause of tSCI is road traffic accident, with falls (especially in elderly population) and violence coming a close second.
4. Male-to-female ratio is roughly 4:1 in USA, with average age at injury being 40 years.
5. Globally, age distribution of tSCI is bimodal, with the first peak between 18 and 29 years with predominantly male patients followed by a second at 65 and above, with an increased number of females.
6. Amongst ntSCI, neoplastic and degenerative diseases are more prevalent in developed world, as against infective in the developing world.
7. Incomplete tetraplegia is the commonest form of presentation.
8. There is not only a paucity of data collection to adequately evaluate the true incidence and prevalence of SCI worldwide; in addition, there is a lack of adherence to collection of minimum data set for meaningful conclusions.

Etiology of SCI—causes and risk factors

Traumatic causes

There are a number of causes of tSCI with significant variation not only between countries but also within the same country.

Motor vehicle accidents

This is the major cause of tSCI in developed world. On a global scale, 50% of all SCI involve road traffic accidents from motor vehicles, bicycles, or pedestrians. Some reliable data from Southeast Asia (Thailand and Vietnam) suggest that the most common cause of tSCI was road traffic accidents with two- or three-wheeled vehicles. In Saudi Arabia, road traffic accidents are still the primary cause of SCI, particularly in the young adults [23]. Alcohol appears to play a major role in adult SCI [24] with a much smaller percentage in which other drugs were associated with SCI.

Violence/self-harm

The etiology of tSCI varies from one country to another. It was higher in North America (15% of all tSCI; almost all of which were firearm-related injuries) than Western Europe (6%), Australia (2%), and Japan (2%) [16]. Violence-related traumatic SCI occurred in regions of conflict or high availability of weapons: high rates of gun-shot injuries were present in the USA and Brazil, with the world's highest proportion in South Africa (35–40% in some areas), making violence the primary cause of SCI in this country.

Falls

Falls especially from trees to rooftops are the major causes of SCI in Southern Asia and Oceania. They remain the second most common cause of SCI worldwide after road traffic accidents. Although in some regions like Nepal, they are the commonest comprising 75% of the SCI due to falls from heights [25]. Older age is a known risk factor for falls. Not surprisingly, falls may exceed traffic accidents as a cause of SCI in the population greater than 65 years of age [26]. Lee et al. found that traumatic SCIs from low falls in the elderly are increasing in developed countries with aging populations, while high falls are more frequent in the developing countries, commonly from trees, balconies, and construction sites; in some developing countries, low falls resulting in traumatic SCI occur while carrying heavy loads on

the head in young people [27]. Japan and Western Europe had a higher rate of falls (42 and 37%, respectively) when compared with Australia and North America (29 and 20%, respectively).

Sports-related SCI

About 10–15% of all of SCI are considered to be sports related [28]. This translates to roughly 1200 new injuries per year with potentially physical and psychological issues. The total direct costs for sports-related SCI in the USA are $694 million per year [29]. Diving-related injuries account for two-thirds of all sports-related SCIs both in the USA and around the world [30]. Recreational diving accounts for the majority of cases. As one might expect, most of the diving injuries occur during the summer months, most occur in males, and the majority of the injuries occur after the consumption of alcohol. The majority of diving-related injuries usually result in complete neurologic lesions as opposed to other sports, which result more often in incomplete deficits. The injury occurs almost exclusively in the cervical spine.

In the USA, football-related SCIs have been extensively studied. In the mid 1950s, hard helmets were introduced. Later on, the development of the tackling techniques known as "spearing" took root in the seventies leading to an increase in SCIs. Hence, this technique was outlawed in 1976. This led to a 50% drop in the number of high school and college football quadriplegic injuries from 1976 [31, 32]. Approximately 40 sports-related cases of vertebral column damage without cord involvement and 7 cases of SCI were reported annually in the USA from 1977 to 2004 [33].

There are significant risks of SCI in other sports like hockey and rugby. In Canada and South Africa, these are the major cause of sport-related injuries [34, 35].

Previously, hyperflexion of the spine was thought to be the mechanism of action for SCI in sporting activities. However, Torg et al. proved that the role of the axial loading that is caused by the blow to the top of the head was the most important factor [36]. The muscles of the neck and shoulder area normally absorb energy that is transmitted from the head to the spine. When enough pressure is generated, the bones, ligaments, and/or discs will fail, causing a cervical injury [37]. The types of injury typically seen at this junction are compression or "burst" fractures. It is generally accepted that primary SCI is most commonly a combination of the initial impact as well as subsequent persisting compression. The primary mechanism involves the initial mechanical injury due to local deformation and energy transformation, whereas the secondary mechanism encompasses a cascade of biochemical and cellular processes that are initiated by the primary process and may cause ongoing cellular damage and even cell death.

Summary of the etiology of SCI

Stover et al. [38] reported from the national database in USA of more than 10,000 cases that the commonest cause of SCI was motor vehicle crashes (47.7%) followed by falls (20.8%), acts of violence—gun-shot wounds and stabbings (14.6%) and sporting related activities (14.2%).

Risk factors

There can be a number of risk factors for sustaining an SCI. Although an SCI does not follow a distinct pattern, the various factors can be described as:

Gender

Young males typically comprise the majority of SCI cases, peaking in the third and fourth decades in most countries. Males are also consistently at greater risk of morbidity and mortality from SCI across all age groups. The ratio of men to women is typically 3–4:1 [4, 38, 39]. The average age at injury has increased from 29 years during the 1970s to 42 years in 2015.

Race

In the US, about 22% of injuries have occurred among non-Hispanic blacks since 2010, which is higher than the proportion of non-Hispanic blacks in the general population (12%) [7]. A significant trend over time has been observed in the distribution of SCI. Between 1973 and 1979, 76.8% were Caucasian, 14.2% were African American, and 0.9% were Asian. Since, 2005, this has changed to 66.1% are Caucasian, 27.1% are African American, and 2.0% are Asian. At the same time, the Hispanic has increased from 6.0 to 8.1% [40]. The changing trend can be attributed to changes in general population along with improvement in reporting models with race-specific incidence rates.

Co-morbidities

A cross-sectional prospective survey was undertaken amongst the members of the Paralyzed Veterans of America in 2003. The respondents were white (82%) men (97%) with more than half having a paraplegic-level injury (52%). They had been injured for an average of 24 years, and had an average age at injury of 36 years. Notably, SCI respondents reported a higher prevalence of several co-morbidities than the general population including *high blood pressure* (49 versus 26%, respectively) and *high cholesterol* (47 versus 30%), and *diabetes* (19 versus 7%). *Obesity* was also a significant problem for individuals with SCI with 25% reporting obesity. It is possible that hypertension might have been over

reported in those with SCI due to the presence of autonomic dysreflexia in this method of self-report.

Infection is a very common cause of re-hospitalization, emergency room visits, and mortality in SCI patients [41, 42].

Individuals with SCI are at increased risk of *bladder cancer*; this cancer is more likely to be diagnosed at a later stage. The incidence of bladder cancer in individuals with SCI is 6‰ with a mean age at diagnosis of 50 years. A majority of studies report a consistent mean of 18–34 years from the onset of the SCI to the diagnosis of bladder cancer. The interval between SCI and the first diagnosis of bladder cancer was 24 years [43–45]. It was thought that indwelling catheters, especially more tan 10 years were a particular risk for developing bladder cancer [46]. However, more recent studies have shown more than 50% of patients developing cancer did not have a catheter, suggesting that neurogenic bladder rather than indwelling catheter is a cancer risk [47].

The tumor subtype is also different in a significant proportion of SCI patients with squamous call cancer implicated in about 37% of patients. The 1-year overall survival rate after treatment of bladder cancer was 62.1%. A number of diagnostic tools have been used including surveillance cystoscopy to detect bladder cancer. This has demonstrated a sensitivity of 64% for detecting bladder cancer. There is no consensus in the literature whether annual screening cystoscopy is useful with some series advocating it is use [8, 47, 48], while others reveal that screening does not lead to an earlier diagnosis in SCI patients who are later diagnosed with bladder cancer [49, 50]. It has been reported that SCI patients who survived their diagnosis of bladder cancer actually had less screening cystoscopies performed than those who died from the disease [50].

Cervical spondylosis is the most common pre-existing abnormality of the spinal column in SCI patients, with a prevalence rate as high as 10% in some series. Spinal cord trauma may be superimposed on and exacerbated by the presence of *congenital abnormalities*, such as atlantoaxial instability, congenital fusions, or tethered cord, and may also occur in the presence of acquired disorders such as metastatic disease, spinal arthropathies such as ankylosing spondylitis, or rheumatoid arthritis. Typically, injuries are worsened or occur with a greater frequency in the face of these associated conditions and, in some cases, would not have occurred had the associated anomaly not been present.

Causes of death

Renal failure was the reported cause of death in 49% of patients with SCI from a 25-year prospective follow-up of 270 SCI patients in the 1970s [51]. A decade later as a consequence of improved urological care the leading causes of death switched to pneumonia, accidents and suicides. An Australian review of mortality data from 335 individuals with tSCI between 1955 and 1994 reported suicide to be among the four leading causes of death for study subjects [52]. The estimated mortality rate was 2.3 times greater than the general population and the suicide rate among SCI subjects was five times greater than among the general population. Most of the death occurred among subjects younger than 39 years [52]. A USA Veterans Administration study of SCI patients over a 25-year period reported suicide rates to be tenfold greater than in uninjured people [53]. One Danish study of 888 individuals with SCI conducted from 1953 to 1990 found that the age-adjusted suicide rate was almost five times greater than that of the general population. The suicide rate was higher among those with less disability than amongst individuals with complete quadriplegia [54].

The suicide rate is thought to be related to depression. This is more prevalent in this subset of population. Kemp and Krause recorded a 31% prevalence rate of depressive disorder in the SCI community, twice the rate of the general population [55].

The average remaining years of life for persons with SCI have not improved since the 1980s and remain significantly below life expectancies of persons without SCI. Mortality rates are significantly higher during the first year after injury than during subsequent years, particularly for persons with the most severe neurological impairments [7].

The patients with SCI in the USA enrolled in the National SCI Database since its inception in 1973. They have now been followed for 40 years. The causes of death that appear to have the greatest impact on reduced life expectancy for this population are pneumonia and septicemia. Mortality rates are declining for cancer, heart disease, stroke, arterial diseases, pulmonary embolus, urinary diseases, digestive diseases, and suicide. However, these gains are been offset by increasing mortality from endocrine, metabolic, nutritional diseases, accidents, nervous system diseases, musculoskeletal disorders and mental disorders. There has been no change in the mortality rate for septicemia in the past 40 years, and only slight decrease in mortality due to respiratory diseases [7].

Conclusions

1. There is a bimodal age distribution of tSCI with the first peak between 18 and 32 years in predominantly male patients followed by a second at 65 and above, with an increased number of females.
2. The younger cohort is secondary to road accidents, the older one predominantly due to falls.
3. Road traffic accidents are the most common cause of traumatic SCI and occur primarily in younger people.
4. The second commonest cause of SCI is falls and these occur primarily in older people.

5. In developed countries, the percentage of people injured over the age of 60 has sharply increased and it is expected that these trends would continue to escalate in line with ongoing population aging.
6. In developed countries, the paraplegia/tetraplegia ratio is decreasing and the frequency of incomplete lesions is increasing.
7. Due to improvements in urological care the death rate from renal disease has decreased.

Pathophysiology

The bladder function is reliant on co-ordination between both central and peripheral nervous systems. There is reciprocal innervation of bladder and external sphincter to facilitate storage and emptying phases. After SCI, either of these can be altered. The classic symptom in a suprasacral SCI is that of urinary incontinence that is most likely secondary to neurogenic detrusor overactivity (NDO). The pathophysiology of NDO can be described as an alteration in the micturition reflex that interrupts this reciprocal innervation leading to dysfunctional voiding pattern with resulting complications.

Afferent pathways

It is postulated that there is a newly developed spinal reflex circuit, which is mediated by C fibers as a response to a reorganization of synaptic connections in the spinal cord. It is thought to be responsible for the development of NDO in response to low volume filling after SCI. In normal micturition, the afferent reflex is carried by Aδ-nerve fibers to dorsal root ganglia. The unmyelinated C fibers are silent under normal conditions. In NDO, this changes and transmission is via unmyelinated C fibers. This leads to a shorted latency period. The direct evidence for this comes from animal experimental models (cats and rats) [56, 57]. However, a comparable process is thought to occur in humans following SCI, with some clinical evidence to support this view [58]. An ultrastructural study from lamina propria of neurogenic bladder revealed that nerve fiber diameter varied in different diseases [59]. In addition, changes in expression of P2X3 and TRPV1 in suburothelium of nerve fibers of NDO bladder have been studied [60]. The investigators demonstrated that there is an increased expression of both P2X3 and TRPV1 in neurogenic bladders as compared to controls. The levels decrease towards normal after successful treatment of NDO with botulinum toxin [60].

Neurotrophic factors

There appears to be some role of various neurotrophic hormones like nerve growth factor (NGF) in the morphological and physiological changes of the bladder afferent neurons leading to the development of neuropathic bladder dysfunction [57, 61]. The evidence of this comes from rat model. The production of neurotrophic factors increases in the bladder after SCI [62, 63]. It has been demonstrated that chronic administration of NGF into the rat bladder induces bladder hyperactivity and increases the excitability of dissociated bladder afferent neurons. On the other hand, intrathecal application of NGF antibodies suppressed neurogenic detrusor overactivity [63] and detrusor sphincter dyssynergia in SCI rats. Animal and human studies also support a role for the suburothelial expression of the transient receptor potential cation channel subfamily V member one (TRPV1), purinergic receptors (P2X3) [64], and/or the sensory neuropeptides substance P (SP) and calcitonin-gene-related peptide (CGRP) [65] in the pathophysiology of human NDO. It has been shown that patients with SCI and NDO have increased TRPV1- and P2X3-immunoreactive suburothelial innervation compared with controls [66].

Spinal cord and vertebral levels

The spinal control of micturition is located at sacral segments 2–4 (vertebral levels of T12–L2) and is described as the primary micturition center [67]. A significant association exists between the level of a spinal cord lesion and the associated bladder dysfunction. In general, on topographic and anatomical basis, when there is injury cephalad to the sacral spinal cord, one expects a voiding pattern consistent with upper motor neuron-type injury with neurogenic detrusor overactivity. In contrast, injury to either the sacral cord or cauda equina segment should result in lower motor neuron-type injury and detrusor hypo/areflexia. Patients with suprasacral spinal cord injuries are also at risk for detrusor-external sphincter dyssynergia secondary to the loss of co-ordination from pons that can lead to incomplete bladder emptying, high post void residual, increased bladder pressure with resulting obstruction of kidneys leading to renal failure [68].

It would appear on the basis of the above categorization that the clinical expression should be clearly characterized. However, this is generally not the case and the clinical manifestations of SCI quite often demonstrate a mixed picture. It has been demonstrated in some studies that there are multiple factors leading to this complicated situation leading to a mismatch between clinical presentation and presumed anatomical level of injury [69]. Some of these factors include:

- Degeneration and reorganization of crucial neural pathways distal to the lesion with or without neural sprouting at the level of injury that may affect the neurologic and urodynamic findings.
- SCI may be incomplete, thereby partially allowing the integration and modulation of complex micturition signals at multiple levels of the nervous system.
- Multiple injuries coexisting at different levels can result in unpredictable mixed voiding dysfunction. The multiplicity of levels of injury is occasionally unrecognized when based solely on urologic history and evaluation in patients with new SCI [69].

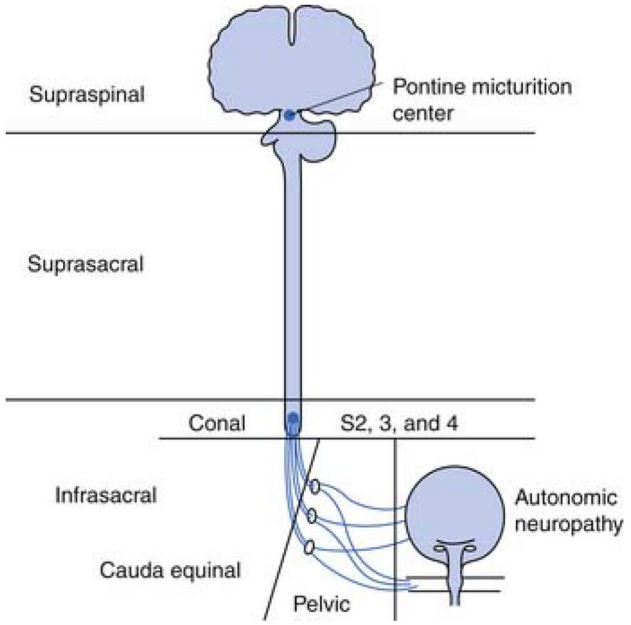

Fig. 1 Levels of injuries in neurogenic lower urinary tract dysfunction

For the purpose of description, if the sacral micturition center (conus medullaris) is taken as a landmark for the convenience of clinical purposes, one can divide the patterns of bladder dysfunction as follows: (Fig. 1).

- Suprasacral lesion: this is an injury anywhere above the level of sacral micturition center but below the pons. The presentating features include detrusor overactivity with external sphincter dyssynergia [68, 70].
- Sacral lesion: this implies the lesion involving the sacral spinal micturition center. This is characterized by detrusor hypo/areflexia with a fixed underactive or denervated striated sphincter.
- Infrasacral lesions including cauda equina: these lesions involve the peripheral nervous system. This includes any injury below the level of sacral micturition center and includes injury to cauda equina and all nerves leading to the bladder or sphincter [71].

Video-urodynamics based classification

The pathophysiology of SCI can also be categorized on urodynamics. This gives a more precise categorization of the bladder/sphincter (dys)function. Urodynamics will demonstrate the lesion regardless of the site and degree of neurologic damage. The disadvantage is that urodynamics findings can be influenced by various factors like UTI, stones, etc. [71, 72]. The urodynamics will demonstrate neurogenic detrusor overactivity in suprasacral SCI (Fig. 2) and detrusor hypo/acontractility with sphincter weakness in sacral and sub-sacral lesions (Fig. 3).

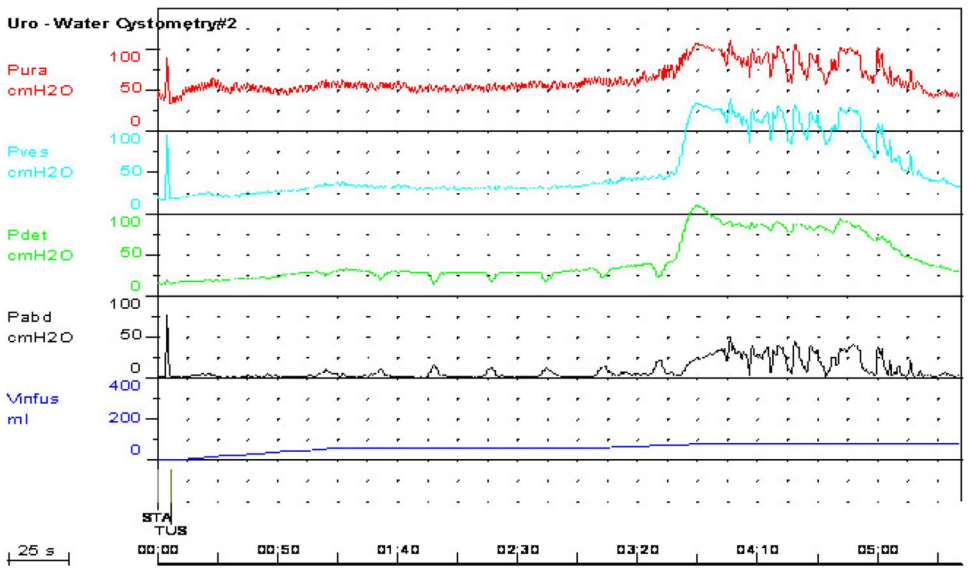

Fig. 2 Detrusor overactivity with detrusor sphincter dyssynergia and reduced bladder compliance typical of a suprasacral SCI

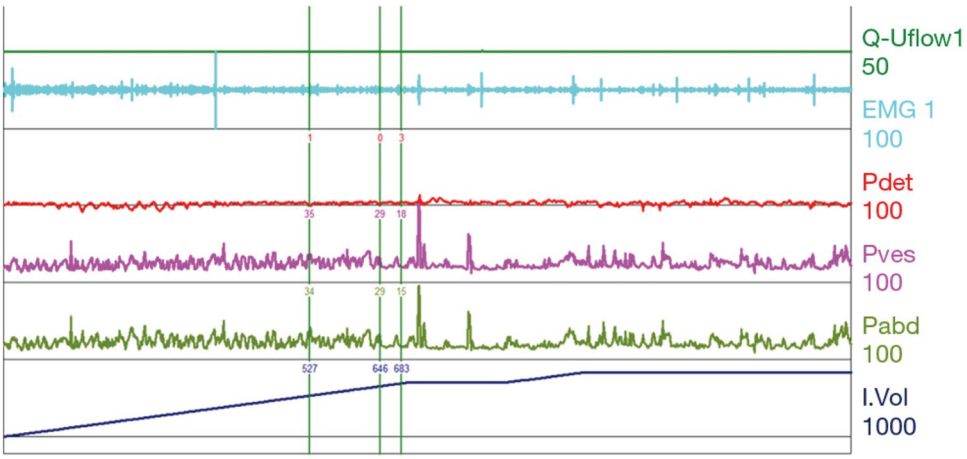

Fig. 3 Detrusor acontractility and large capacity bladder typical of a sacral SCI

Clinically based classification

Wein et al. [72] classified voiding dysfunction after SCI based on symptoms as follows:

- Storage failure: this includes either an overactive bladder or underactive sphincter. It can also lead to loss of compliance. The symptoms will include frequency, nocturia, urgency with/without incontinence.
  An underactive sphincter could lead to stress-related urinary incontinence.
- Emptying failure: this includes either a bladder that is underactive or a sphincter that is overactive.

It is important to point out that quite often, there is not a clear cut presentation as stated above and there can be a storage failure in suprasacral SCI due to detrusor overactivity or reduced compliance, as well as in sacral SCI due to weak sphincter. On the other hand, emptying failure can occur in suprasacral SCI due to a fibrotic bladder or DSD, as well as in sacral SCI due to flaccid bladder.

Clinically based classification with urodynamics correlation

One can combine the symptoms and associated urodynamics findings to better understand the pathophysiology [73, 74].

- Lesions above the brain stem: the symptoms will include urinary frequency, urgency, with or without urge urinary incontinence. The bladder sensation can be normal or decreased. The urinary sphincters should be synergistic with the bladder and relax when the bladder contracts. The urodynamics will demonstrate NDO but no DSD with possible incomplete emptying especially in the elderly.
- Suprasacral spinal cord lesions: the symptoms would be the same as above brain stem but can be more severe with incomplete emptying, urinary infections but importantly due to DSD can lead to autonomic dysreflexia in lesions above T6 level. The accompanying urodynamics will demonstrate NDO but with DSD and incomplete emptying.
- Sacral lesions: the symptoms could be delayed sensations with stress-related urinary incontinence. The urodynamics will demonstrate poorly contracting detrusor with incomplete emptying. It might also show a weak sphincter.
- Injury distal to the spinal cord: the sensations to bladder filling could be normal to decreased. The urodynamics could show detrusor areflexia. The internal sphincter is likely incompetent, and the striated external sphincter may exhibit fixed residual tone that cannot be relaxed voluntarily.

Conclusions

1. SCI leads to NLUTD in about 70–84% of patients.
2. Two decades ago, urinary tract mortality was ranked as the second leading cause of death in the SCI patient but with significant improvement in understanding and management of this condition urinary disease now accounts for only ≈ 13% of deaths (LoE 3).
3. It is postulated that a new spinal reflex circuit develops which is mediated by C fibers as a response to a reorganization of synaptic connections in the spinal cord. This is thought to be responsible for the development of neurogenic detrusor overactivity in response to low volume filling after SCI (LoE 4).
4. Various neurotrophic hormones like nerve growth factor affect the morphological and physiological changes of the bladder afferent neurons leading to the development of neuropathic bladder dysfunction (LoE 3).

5. A suprasacral SCI usually results in a voiding pattern consistent with upper motor neuron-type injury with neurogenic detrusor overactivity and DSD (LoE 3).
6. Injury to either the sacral cord or cauda equina segment should result in lower motor neuron-type injury and detrusor hypo/areflexia (LoE 3).
7. The urodynamics will demonstrate neurogenic detrusor overactivity with sphincter dyssynergia in suprasacral SCI and detrusor hypo/acontractility with sphincter weakness in sacral and sub-sacral lesions (LoE 3).
8. Suprasacral SCI may lead to incomplete emptying, urinary infections and DSD; they are also associated with autonomic dysreflexia in lesions above T6 level (LoE 3).
9. Sacral SCI may lead to delayed sensation during bladder filling and to stress urinary incontinence (LoE 3).
10. Injury distal to the spinal cord may (cauda equina injury) lead to a bladder with normal sensations with an incompetent internal sphincter and the striated external sphincter exhibiting fixed residual tone that cannot be relaxed voluntarily (LoE 3).

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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