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Ville Niemi-Nikkola

SPINAL FRACTURES AND SPINAL CORD INJURIES

INCIDENCE, EPIDEMIOLOGICAL CHARACTERISTICS AND SURVIVAL

*UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU,
FACULTY OF MEDICINE*

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VILLE NIEMI-NIKKOLA

SPINAL FRACTURES AND SPINAL CORD INJURIES

Incidence, epidemiological characteristics and survival

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Supervised by
Doctor Aki Vainionpää
Professor Mauri Kallinen

Reviewed by
Professor Hannu Aro
Doctor Ellen Merete Hagen

Opponent
Professor Jari Arokoski

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University of Oulu, P.O. Box 8000, FI-90014 University of Oulu, Finland

Abstract

Trauma to the spine can have serious consequences, such as traumatic spinal fracture, traumatic spinal cord injury or both. In addition to traumatic causes, the spinal cord can also be injured due to non-traumatic causes, referred to as a ‘non-traumatic spinal cord injury’.

The aim of this thesis was to reveal the epidemiological characteristics of traumatic spinal injuries in Northern Finland, the long-term mortality and causes of death after traumatic spinal fractures and the epidemiological characteristics of non-traumatic spinal cord injuries in Finland.

The study sample consisted of 971 traumatic spinal injury patients and 947 traumatic spinal fracture patients treated in Oulu University Hospital between 2007 and 2011, and 430 non-traumatic spinal cord injury patients treated in Tampere University Hospital and Oulu University Hospital in a four-year period between 2012 and 2016.

The annual incidence of traumatic spinal injury in Northern Finland was 26/100,000. Low falls were the most common trauma mechanism, which differed from most previous studies. They caused a majority of the injuries in older age groups (i.e., over 60 years old). In contrast, in younger age groups (i.e., under 45 years old), road traffic accidents were clearly overrepresented. Mortality after traumatic spinal fracture was increased in all age groups compared to the general population, varying from threefold in those over 65 years old to twentyfold in those under 30 years old. Low fall as a trauma mechanism increased the hazard for death in the long term significantly compared to high-energy mechanisms.

The incidence of non-traumatic spinal cord injury was 54/1,000,000 per year, which was remarkably higher than that reported in previous international results. This indicates that the centralisation of spinal cord injury care in Finland in 2011 has made possible the study of the entire non-traumatic spinal cord injury patient group. Degenerative diseases were the most common aetiology, followed by malignant and benign neoplasms.

The main targets for traumatic spinal injury prevention should be low falls in the elderly and road traffic injuries in the younger population. The mortality after traumatic spinal fracture is high and seems to be comparable to the mortality after hip fracture reported in previous international studies. The incidence of non-traumatic spinal cord injury was higher than excepted. The reported high incidence indicates that study designs should be carefully considered in future international studies.

Keywords: accidental falls, cause of death, epidemiology, incidence, mortality, non-traumatic spinal cord injuries, spinal cord injuries, spinal fractures, spinal injuries, survival, trauma

Niemi-Nikkola, Ville, Selkärankamurtumat ja selkäydinvammat. Ilmaantuvuus, epidemiologiset piirteet ja kuolleisuus
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Tiivistelmä

Usein vakavia seurauksia aiheuttaviin tapaturmaisiin selkärankavammoihin sisältyy selkärankamurtumat ja tapaturmaiset selkäydinvammat. Tapaturmaisten vammojen lisäksi selkäydinvamman voi aiheuttaa myös sairausperäinen syy, kuten kasvain.

Väitöstutkimuksessa oli tavoitteena selvittää tapaturmaisten selkärankavammojen ja sairausperäisten selkäydinvammojen epidemiologisia piirteitä sekä tapaturmaisten selkärankamurtumien jälkeistä kuolleisuutta ja kuolinsyitä.

Tutkimusotos muodostui 971:stä tapaturmaisen selkärankavamman ja 947:stä tapaturmaisen selkärankamurtuman vuosina 2007–2011 saaneesta, Oulun yliopistollisessa sairaalassa hoidetusta potilaasta sekä 430:stä sairausperäisen selkäydinvamman saaneesta Tampereen ja Oulun yliopistollisissa sairaaloissa vuosina 2012–2016 hoidetusta potilaasta.

Selkärankavammojen vuotuinen ilmaantuvuus Pohjois-Suomessa oli 26/100 000. Yleisin vammamekanismi oli kaatuminen. Vammamekanismit vaihtelivat ikäryhmittäin: yli 60-vuotiailla suurin osa tapaturmista johtui kaatumisista, kun taas alle 45-vuotialla liikennetapaturmat olivat suurin yksittäinen syy. Selkärankamurtuman jälkeinen kuolleisuus oli korkeampi kuin normaaliväestöllä, vaihdellen kolminkertaisesta yli 65-vuotiailla kaksikymmenkertaiseen alle 30-vuotiailla. Kaatuminen vammamekanismina nosti kuolemanriskiä merkittävästi verrattuna korkeaenergisiin vammamekanismeihin. Sairausperäisten selkäydinvammojen vuotuinen ilmaantuvuus oli 54/1 000 000. Ilmaantuvuus oli aikaisempien kansainvälisten julkaisujen tuloksiin verrattuna huomattavan korkea, mikä viittaa siihen, että vuonna 2011 toteutuneen selkäydinvammojen hoidon keskittämisen ansiosta pystyimme huomioimaan koko potilasryhmän. Yleisimmät etiologiat olivat selkärangan rappeumasairaudet sekä pahan- ja hyvänlaatuiset kasvaimet, tässä järjestyksessä.

Tapaturmaisten selkärankavammojen ehkäisyssä tulisi keskittyä kaatumisten ehkäisyyn ikääntyneillä ja toisaalta liikennetapaturmien ehkäisyyn nuorilla. Selkärankamurtumien jälkeinen kuolleisuus on merkittävää, ja se on verrattavissa aikaisemmin julkaistuihin lonkkamurtuman jälkeisiin kuolleisuuslukuihin. Kaatumisen seurauksena selkärankamurtuman saaneet tarvitsevat erityistä huomiota hoidossa merkittävän kuolemanriskin takia. Sairausperäisten selkäydinvammojen ilmaantuvuus oli odotettua korkeampi. Korkea ilmaantuvuus korostaa tutkimusasetelman valinnan tärkeyttä tulevissa tutkimuksissa.

Asiasanat: epidemiologia, ilmaantuvuus, kaatumistapaturmat, kuolinsyy, kuolleisuus, sairausperäiset selkäydinvammat, selkärangan murtumat, selkärankavammat, selkäydinvammat

To my family

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Helsinki, May 2020 Ville Niemi-Nikkola

Abbreviations

AIS	American Spinal Injury Association Impairment Scale
AS	Ankylosing spondylitis
ASIA	American Spinal Injury Association
ASOI	Associated injury
C	Cervical
CT	Computed tomography
DISH	Idiopathic skeletal hyperostosis
EYOLL	Estimated years of life lost
FIM	Functional Independence Measure
HIV	Human immunodeficiency virus
HR	Hazards ratio
ICD-10	10th revision of the International Statistical Classification of Diseases and Related Health Problems
ICU	Intensive care unit
ISCoS	International Spinal Cord Society
ISNCSC	International Standards for Neurological Classification
ISS	Injury Severity Score
L	Lumbar
LOS	Length of stay
MRI	Magnetic resonance imaging
NCSP	Nordic Classification of Surgical Procedures
NTSCI	Non-traumatic spinal cord injury
OR	Odds ratio
PLC	Posterior ligamentous complex
SCI	Spinal cord injury
SD	Standard deviation
SMR	Standardised mortality ratio
TBI	Traumatic brain injury
Th	Thoracic
TLICS	Thoracolumbar Injury Classification and Severity Score
TNF-α	Tumour necrosis factor alpha
TSCI	Traumatic spinal cord injury
TSF	Traumatic spinal fracture
TSI	Traumatic spinal injury
UH	University Hospital

List of original publications

This thesis is based on the following publications, which are referred to throughout the text by their Roman numerals:

I Niemi-Nikkola, V., Saijets, N., Ylipoussu, H., Kinnunen, P., Pesälä, J., Mäkelä, P., Alen, M., Kallinen, M., & Vainionpää, A. (2018). Traumatic Spinal Injuries in Northern Finland. *Spine, 43*(1), E45–E51. https://doi.org/10.1097/BRS.0000000000002214

II Niemi-Nikkola, V., Saijets, N., Ylipoussu, H., Kinnunen, P., Pesälä, J., Mäkelä, P., Alen, M., Kallinen, M., & Vainionpää, A. (2018). Long-term Posttraumatic Survival of Spinal Fracture Patients in Northern Finland. *Spine*, *43*(23), 1657–1663. https://doi.org/10.1097/BRS.0000000000002687

III Niemi-Nikkola, V., Koskinen E., Väärälä E., Kauppila, A., Kallinen M., & Vainionpää, A. (2020). Incidence of Acquired Nontraumatic Spinal Cord Injury in Finland: A 4-Year Prospective Multicenter Study. (2020). *Archives of Physical Medicine and Rehabilitation.* Advance online publication. https://doi.org/10.1016/j.apmr.2020.08.015

Contents

1 Introduction

Traumatic spinal injuries (TSIs) are potentially devastating injuries caused by a blunt or penetrating trauma to the spinal columns, spinal cord or discoligamentous components of the spine (Kumar et al., 2018). In a clear majority of TSI patients, traumatic spinal fracture (TSF) occurs, which may lead to further associated injuries (ASOIs) including traumatic spinal cord injury (TSCI) in one-tenth to one-fifth of cases (Fletcher et al., 1995; Oliver et al., 2012). Spinal cord injury (SCI) can also arise from many causes other than trauma, referred to then as 'non-traumatic spinal cord injury' (NTSCI; the terms 'spinal cord damage', 'spinal cord myelopathy' and 'spinal cord dysfunction' are also used; (New & Marshall, 2014).

Internationally, the annual incidence of TSF has varied from 16–64/100,000, depending on the study area and population concerned (Hu, Mustard, & Burns, 1996; Moradi-Lakeh et al., 2011). High-energy injuries such as road traffic accidents and high falls are the typical aetiology in young patients, whereas the role of low falls and associated osteoporosis increases in older patients. In Finland, the annual incidence of TSF requiring inpatient care has been reported to be 27/1,000,000 in the Central Finland Hospital District (Somersalo et al., 2014). Otherwise, no previous epidemiological data related to TSF has been reported in Finland prior to the present study.

TSF, with or without accompanying SCI, often leads to a decrease in quality of life and a loss of functioning and work capacity (Bouyer et al., 2015; Post & van Leeuwen, 2012; Schouten et al., 2014). The financial burden of this upon society is remarkable; for example, in Australia, the average cost of hospitalisation due to TSI was found to be AU$23,800 (€14,750) per patient under 65 years old and AU$31,200 (€19.700) per patient over 65 years old (Mitchell, Harvey, Stanford, & Close, 2018). Further, the lifetime costs after a possibly associated spinal cord lesion have been estimated to vary between US$1.7 million (€1.5 million) and US$5.0 million (€4.5 million) if injured at the age of 25 in the United States (US; National Spinal Cord Injury Statistical Center, 2019). In addition to the economic burden, existing spinal injury is known to increase mortality in trauma patients, and increased mortality after TSCI is well documented (Ahoniemi, Pohjolainen, & Kautiainen, 2011; Akmal, Trivedi, & Sutcliffe, 2003). Most of the previous studies about mortality after TSF, however, have focused on specific types of fractures or have only documented short-term mortality. The standardised mortality ratio (SMR) after osteoporotic spinal fracture has been reported to be 2.4–2.5 for men and 1.7–1.9 for women (Bliuc et al., 2009; Center, Nguyen, Schneider, Sambrook, &

Eisman, 1999). In-hospital mortality after TSF, in contrast, has varied between 0.1% and 4% in previous studies (Hu et al., 1996; Kattail, Furlan, & Fehlings, 2009; Wang et al., 2012; Williams et al., 2014). However, it is known that the long-term mortality after trauma is significant, indicating that reporting only the short-term mortality is not adequate when studying mortality (Davidson et al., 2011).

When it comes to the research related to SCI, there has thus far been a focus on TSCI rather than NTSCI, regardless of the fact that NTSCIs are reported to be more common than TSCIs (Ge et al., 2018; New & Sundararajan, 2008; Noonan et al., 2012). There is only limited number of studies about the epidemiology of NTSCI. A global review reported a median annual incidence of 6/1,000,000 in Western Europe (New, Cripps, & Bonne Lee, 2014). In Norway, the incidence has recently been reported to be 7.7–10.4/1,000,000 (Halvorsen et al., 2019b). The above are low figures compared to the reported incidence of 68/1,000,000 in Canada (Noonan et al., 2012). The most common aetiologies for NTSCI seem to be degenerative diseases and neoplasms in developed countries, and infections and neoplasms in developing countries (New et al., 2014).

In 2011, the acute treatment, rehabilitation and lifelong follow-up of SCI patients became centralised in three university hospitals (UHs) in Finland (Ministry of Social Affairs and Health, 2010). This centralisation offers a great opportunity for epidemiological research, allowing for better coverage of SCI patients. The incidence of TSCI, which was hidden prior to centralisation, has now been revealed (Koskinen et al., 2014). However, epidemiological data on NTSCI in Finland has been missing.

The main goal of the present study is to reveal the incidence and other epidemiological characteristics, such as the aetiology and outcome, of TSIs in Northern Finland and NTSCIs in Finland. In addition, the study aims to clarify the long-term mortality and the risk factors for death after TSF.

2 Review of the literature

2.1 Spinal injuries

2.1.1 Anatomy of the spine and the spinal cord

In this chapter, the anatomy of the spine and the spinal cord is described, according to Drake et al. (2015) and Jallo & Vaccaro (2018).

The spine (vertebrae) is part of the musculoskeletal complex in the back that supports the body's weight and protects the spinal cord. It usually consists of 33 bony vertebrae: seven cervical (CI–CVII), twelve thoracic (ThI–ThXII), five lumbar (LI–LV), five sacral (SI–SV) and four coccygeal vertebrae (Figure 1). The sacral vertebrae fuse into a single sacrum, and the coccygeal vertebrae into a single coccyx. The sacrum articulates on each side with pelvic bones, being a component of the pelvic ring.

CI (atlas) and CII (axis) have unique anatomies compared to the rest of the spine, while the cervical spine below CI and CII has a similar vertebral anatomy (with some exceptions) to that of the thoracic and lumbar spine; together, these are considered as a group, the subaxial spine. A typical subaxial vertebra consists of a vertebral body and a vertebral arch. The vertebral body is the anterior part of the spine and bears most of the weight. Vertebral bodies are connected to each other with fibrocartilaginous structures called 'intervertebral discs'. The vertebral arch forms a bony spinal canal that extends from the first cervical vertebrae to the last sacral vertebra. Together with fat and connective tissue, the spinal canal contains the spinal cord, its protective membranes and proximal spinal nerves. A spinous process posteriorly and two transverse processes protect the spinal canal.

The most important anterior ligaments of the spine are anterior longitudinal ligament, which insert into the base of the skull and extend to the anterior surface of the sacrum and posterior longitudinal ligament, which lies on the posterior surfaces of the vertebral bodies. The most important posterior ligaments form an important stabilising structure called the 'posterior ligamentous complex' (PLC) (Khurana, Sheehan, Sodickson, Bono, & Harris, 2013). The PLC includes articular facet capsules, ligament flava (which form part of the posterior surface of the spinal canal), the interspinous ligaments pass and the supraspinous ligament.

The cervical and lumbar spine have lordotic curvatures, whereas the thoracic spine has a kyphotic curvature. Partly due to its attachment to the rib cage, the thoracic spine is also more rigid than are the lumbar and cervical spine. These regional differences make junction points of the spine more prone to fractures and are important to consider in treatment planning.

The spinal cord lies in the spinal canal extending from the foramen magnum of the skull usually to the first or second lumbar vertebra. The most inferior part of the spinal cord is called the ‘conus medullaris’, and below the conus medullaris lumbar, sacral and coccygeal nerves form the cauda equina. The spinal cord consists of grey matter rich in cell bodies and white matter rich in nerve cell processes. Grey matter has an H-shaped appearance in the horizontal plane and is surrounded by white matter, which forms nerve tracts ascending between spinal cord levels or carrying signals from and to the brain.

The spinal cord is surrounded by three meninges: the dura mater, the arachnoid mater and the pia mater. The blood supply to the spinal cord derives from longitudinal and segmental spinal arteries. Longitudinally oriented arteries include a single anterior spinal artery derive from vertebral arteries and two posterior spinal arteries arising from the posterior inferior cerebellar arteries. The segmental spinal arteries derive from the vertebral and deep cervical arteries in the cervical region, the posterior intercostal arteries in the thoracic region and the lumbar arteries in the lumbar region.

Thirty-one pairs of spinal nerves originate from the spinal cord: eight cervical (C1–C8), twelve thoracic (T1–T12), five lumbar (L1–L5), five sacral (S1–S5) and one coccygeal nerve pair (Co). Except for C1, the spinal nerves exit the spinal canal through intervertebral foramens. C2–C7 emerge between the foramens above their respective vertebrae, and as there are only seven cervical vertebrae, the rest, starting from C8, emerge below their respective vertebrae. Each spinal nerve is connected to the spinal cord by rootlets forming an anterior root, which contains sensory neurons, and posterior roots, which contain motor nerve fibres. The area in the spinal cord from which each spinal nerve’s rootlets arise is called a ‘spinal segment’.

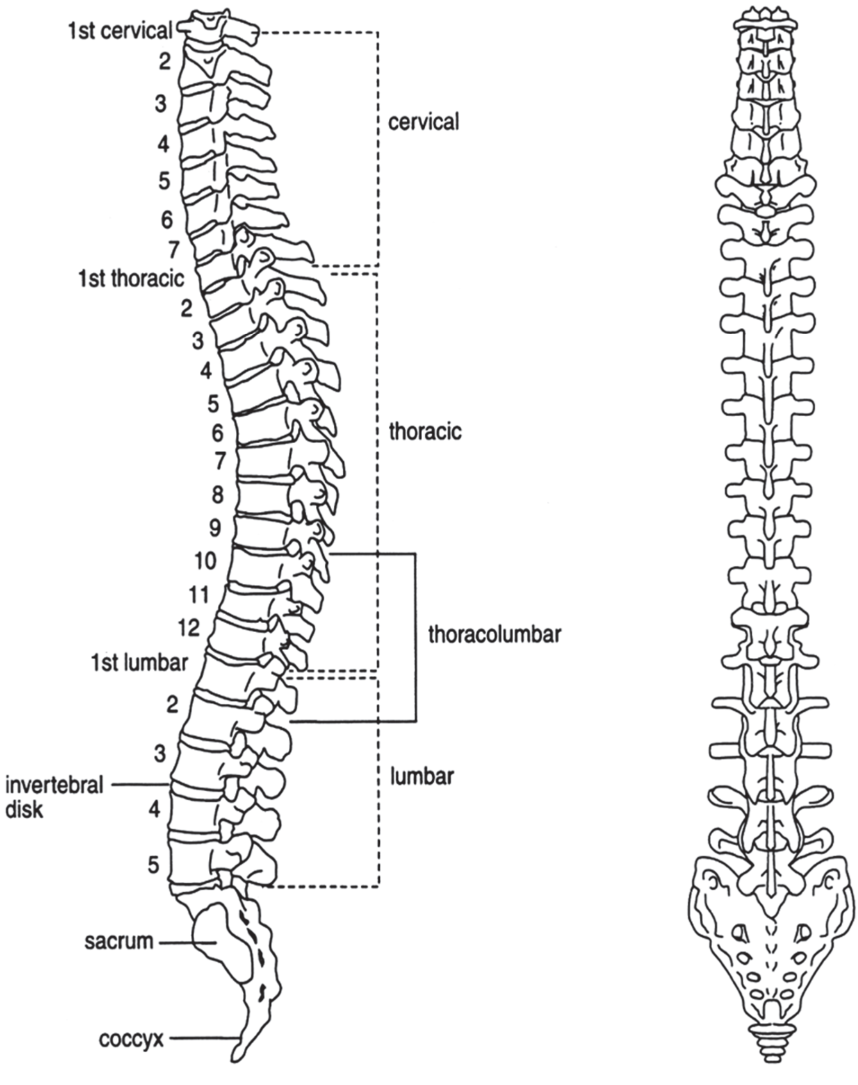

Fig. 1. Anatomy of the spine.

2.1.2 Spinal fractures

The cervical and lumbar spine are flexible, whereas the thoracic spine and sacrum are rigid, and fractures of the spine tend to be located at junctions of these flexible and rigid parts. Due to the different anatomy involved in upper cervical fractures compared to fractures in the rest of the spine, they tend to have unique characteristics. Fractures of the coccyx play a minimal clinical role and are not discussed in this thesis.

Spinal fractures can occur due to high- and low-energy mechanisms. Osteoporosis has a role in low-energy-induced fractures, and it must also be taken into account that some osteoporotic vertebral compression fractures are asymptomatic (morphometric) and do not garner clinical attention (Kendler et al., 2016). However, it is important to emphasise that in this thesis, only TSFs are discussed. In addition to osteoporosis, ankylosing spondylitis (AS) and diffuse skeletal hyperostosis (DISH) increase the risk for spinal fracture, and highly unstable fracture patterns can occur in the spine with these conditions, often with minimal trauma (Jallo & Vaccaro, 2018).

Subaxial cervical (CIII–CVII) and thoracolumbar (ThI–LV) fractures can be classified in three main categories depending on the bony anatomy and injury mechanism, according to AO classification: type A fractures are compression injuries with an intact tension band, type B fractures are distraction injuries including tension band injury and type C fractures are unstable translational injuries (Schnake, Schroeder, Vaccaro, & Oner, 2017). In guiding treatment and predicting outcomes not only are the injury mechanism and anatomical aspects crucial but also the neurological status of the patient and integrity of the PLC. The Thoracolumbar Injury Classification and Severity Score (TLICS) combines these factors to assist in clinical management by stratifying patients into stable and unstable groups, and suggests surgical or nonsurgical treatment (Vaccaro et al., 2005).

The vertebrae of the upper cervical spine are anatomically unique, enabling rotation of the neck and weight transfer between the head and trunk, a reason why fractures in this level are also unique (Jackson, Banit, Rhyne, & Darden, 2002). The integrity of the transverse alar ligament is the most important factor in deciding the treatment for atlas (C1) fractures, whereas in odontoid (C2, axis) fractures, the treatment choice is more multifactorial (Bransford, Alton, Patel, & Bellabarba, 2014). Atlantoaxial dislocation is usually treated surgically, and Hangman's fracture of the axis (C2) is treated non-operatively for the most part (Bransford et al., 2014).

The sacrum is part of the pelvic ring, and fractures here are often associated with other pelvic ring injuries. Sacral fractures are usually longitudinal, transverse or combination of these, with longitudinal fractures being the most common type

(Beckmann & Chinapuvvula, 2017). Determining the level of stability and the course of treatment can be challenging. Generally, transverse fractures below the S3 level, and impacted and partial longitudinal fractures are considered to be stable, whereas complete longitudinal and displaced transversal fractures above the S3 level are considered unstable (Beckmann & Chinapuvvula, 2017).

2.1.3 Spinal cord injuries

Spinal cord injuries can be divided into TSCIs and NTSCIs, depending upon their aetiology. Examples of these injuries are seen in Figures 2 and 3.
Generally, in SCI, a mechanical force—caused by a fracture or a tumour, for example—leads to damage to the spinal cord. The direct compression of the mechanical force, such as that caused by a fracture or epidural haematoma, injures neural and vascular elements of the spinal cord and leads to micro-haemorrhages and swelling of the spinal cord (McDonald & Sadowsky, 2002). The primary injury is followed by progressive secondary injury, which expands the neural tissue damage (Ahuja et al., 2017). Inflammatory cells infiltrate the injury site and release inflammatory cytokines such as tumour necrosis factor alpha (TNF-α). Also, the loss of ionic homeostasis causes intracellular hypercalcemia, which eventually leads to apoptosis. Reactive oxygen species released by inflammatory cells further induce apoptosis (Ahuja et al., 2017). In traumatic injuries or acute-onset non-traumatic injuries, a temporary spinal shock phase due to dysfunction of the autonomic nervous system is present (Atkinson & Atkinson, 1996).

The main features of SCI are the relatively symmetric paralysis of the limbs, urinary retention or incontinence, and the loss of sensation below a circumferential level, called the 'sensory level' (Ropper & Ropper, 2017). Clinical findings vary depending upon the injury level. They often include hyperreflexia and positive Babinski signs; however, in spinal shock, limbs may be flaccid and areflexic together with exhibiting systemic hypotension (Ropper & Ropper, 2017). Also, in injuries below the conus medullaris (usually L1–L2, cauda equina), flaccid paraparesis and early incontinence are present. In addition to motor and sensory deficiencies, cardiovascular, thermoregulatory and bronchopulmonary instabilities are often present after SCI injuries above the sixth thoracic vertebrae (Th6) due to dysfunction of the autonomic nervous system (Hagen, 2015). SCI can also affect the respiratory muscles, and patients with an injury level of the third cervical vertebra (C3) and above may be ventilatory-dependent (Nas, Yazmalar, Sah, Aydin,

& Ones, 2015). Moreover, SCI is often associated with bowel problems, sexual and bladder dysfunction, pain, spasticity and depressive disorders (Hagen, 2015).

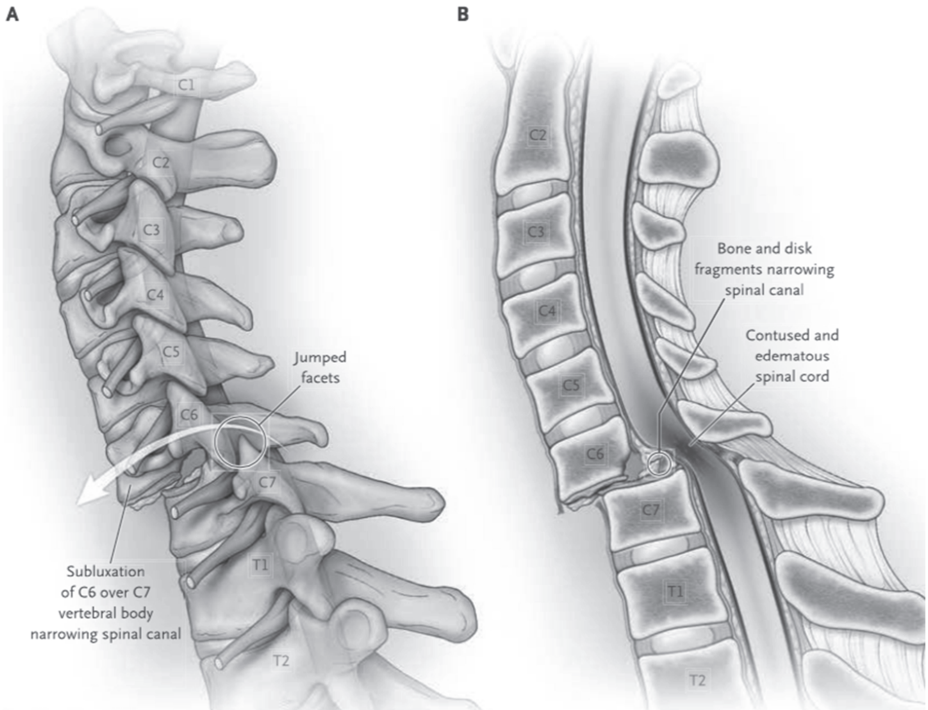

Fig. 2. A traumatic spinal cord injury due to traumatic spondylolisthesis in the sixth and seventh cervical spinal column. Bone and disc fragments from a fracture in the narrow spinal canal result in contusion and oedema in the injury level, also extending caudally and cranially. Reproduced with permission from Ropper & Ropper (2017). Copyright Massachusetts Medical Society.

As said, the clinical features of SCIs vary depending on the injury level and completeness of the injury. A neurological level of injury is described as the most caudal segment, allowing normal sensory and antigravity motor function (DeVivo et al., 2006) With the exception of a central cord syndrome, SCI usually causes impairment in motor and/or sensory function in all levels below the neurological level (Rogers & Todd, 2016). The ASIA Impairment Scale (AIS) is used in grading impairment (Kirshblum et al., 2011). AIS A is a complete injury, meaning full loss of motor and sensory function below the neurological level. AIS B–D are incomplete injuries, as seen in Table 1, in which the AIS scores are presented. The most common types of incomplete SCI include central cord syndrome, anterior cord syndrome, posterior cord syndrome and Brown-Sequard syndrome (Nowak, Lee, Gelb, Poelstra, & Ludwig, 2009). The syndromes form a wide spectrum of injuries, varying in clinical features. For example, central cord syndrome, the most common incomplete injury, is most often caused by hyperextension injuries in degenerative cervical spines; the injury more often affects upper arms than lower limbs and more often causes motor than sensory deficits (Molliqaj, Payer, Schaller, & Tessitore, 2014).

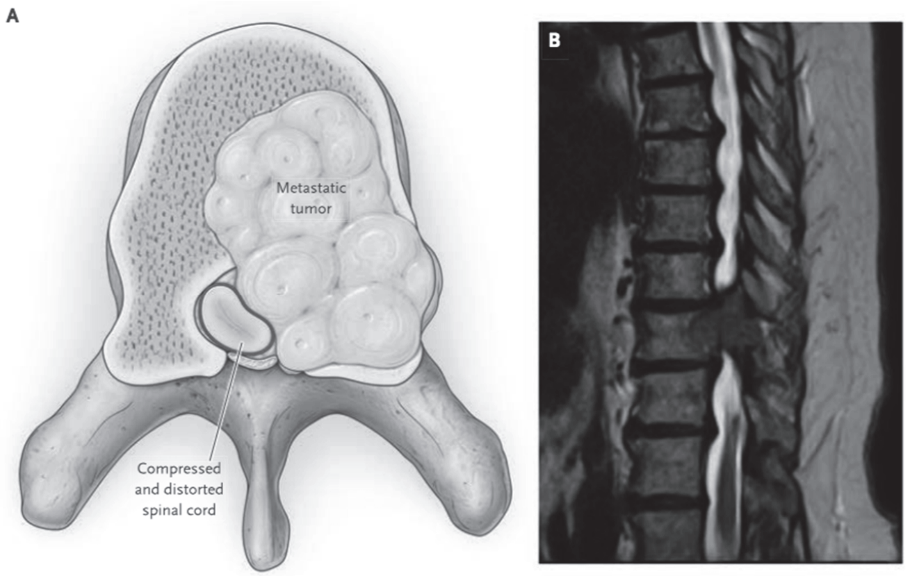

Fig. 3. An example of non-traumatic spinal cord injury caused by a metastatic tumour in a thoracic spinal column. The tumour narrows the spinal canal causing distortion and compression of the spinal cord. On the right, a T2-weighted magnetic resonance imaging (MRI) scan shows metastatic renal cancer on the tenth thoracic spinal column, narrowing the spinal canal. Reproduced with permission from Ropper & Ropper (2017). Copyright Massachusetts Medical Society.

In tetraplegia, cervical level SCI results in the impairment of motor and/or sensory function in the arms and usually in the trunk, pelvic organs and legs. In contrast, in paraplegia caused by thoracic, lumbar or sacral SCI, the function of the trunk, pelvic organs and legs are impaired depending on the level of the injury, but the function in the arms is spared (Nas et al., 2015).

In the treatment and rehabilitation of SCI patients, a multidisciplinary approach is needed. The treatment process is long, starting with acute care—often including surgical stabilisation of the spine—and continuing with sensory, motor and autonomic dysfunction treatment in the chronic phase and, finally, lifelong treatment in the home environment (Nas et al., 2015).

Table 1. ASIA Impairment Scale according to Kirshblum et al. (2011) and the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSC).

AIS grade	Injury	Description
AIS A	Complete	No sensory or motor function is preserved in sacral segments S4–S5.
AIS B	Sensory incomplete	Sensory but not motor function is preserved below the neurological level and includes sacral segments S4–S5, and no motor function is preserved more than three levels below the motor level on either side of the body.
AIS C	Motor incomplete	Motor function is preserved below the neurological level,[1] and more than half of key muscle functions below the single neurological level of injury have a muscle grade less than 3 (Grades 0–2).
AIS D	Motor incomplete	Motor function is preserved below the neurological level,[1] and at least half of key muscle functions below the neurological level of injury have a muscle grade over 3.
AIS E	Normal	Sensation and motor function are graded as normal in all segments. Individuals without SCI do not receive an AIS grade.

[1]To be graded as AIS C or D, there must be either voluntary sphincter tonus or sparing of the motor function at more than three levels below the motor level of the same side with sacral sensory sparing. In determining motor incomplete status, even non-key muscles functioning three levels below the motor level are used (AIS B vs AIS C).

2.1.4 Spinal injury care

Acute care of spine trauma patients

In this section, a brief overview of the general principles of the acute care of spine trauma patients is provided. As much as 72% of TSI patients have been reported to have ASOIs. For example, head injuries (possible traumatic brain injury [TBI]) have been reported to be represented in 14–26% of patients (Hu et al., 1996; Leucht, Fischer, Muhr, & Mueller, 2009; Saboe, Reid, Davis, Warren, & Grace, 1991; Wang et al., 2012). It is important to note that the treatment of polytrauma patients is a vast entity starting with maintaining the vital functions of the patient, and the treatment of spinal injury overviewed in this chapter is only a part of that entity.

When evaluating trauma patients, a possible spine trauma requires spinal immobilisation with a rigid collar, backboard and precautions for patient transfer until the diagnosis is clear and the stability of the possible fracture is determined. Especially in high-risk groups, such as the elderly, patients with osteoporotic spine or ankylosing spondylitis, special attention is needed, as fractures can occur with minimal energy. Also, when assessing unconscious trauma patients, spinal trauma should always be suspected. In the early evaluation of a spine trauma patient, a focused yet thorough neurological examination is critical to recognise possible SCI (Eckert & Martin, 2017). Computed tomography (CT) is the radiological gold standard for spine trauma in acute care, and an early MRI is also often needed if SCI is suspected (Ahuja et al., 2017). Operative treatment is usually dictated when fracture leads to the loss of the mechanical stability of the spine (making the fracture unstable) or to the injury of nervous structures. There are many operative techniques using either an anterior, a posterior or a combined surgical approach (Wood, Li, Lebl, & Ploumis, 2014). Stable spinal fractures, in contrast, are usually treated non-operatively with early mobilisation using orthoses or no external support at all in thoracolumbar fractures, or with a collar in cervical fractures (Peck, Shipway, Tsang, & Fertleman, 2018; Wood et al., 2014).

When it comes to the acute care of SCI patients, hypoxia and hypotension should be corrected, as they lead to further neurological injury (Eckert & Martin, 2017). A multidisciplinary approach is needed with the surgical treatment of immediate life- or limb threatening injuries maintaining spinal immobilisation and often also treatment in intensive care unit (ICU) is required (Ahuja et al., 2017). In the care of SCI resulting from a compressive cause, such as epidural hematoma, fracture, abscess or haemorrhage, an early surgical decompression within 8–24 hours is associated with improved neurological outcomes in incomplete SCI (Ahuja et al., 2017; Eckert & Martin, 2017). The role of steroids in the acute care of SCI remains controversial (Ahuja et al., 2017; Eckert & Martin, 2017). After stabilisation of the patient, transfer to a specialised SCI centre is associated with better neurological recovery (Ahn et al., 2011).

Rehabilitation of spinal cord injury patients

TSCI and NTSCI patients both benefit from rehabilitation in specialized SCI centres (New, Simmonds, & Stevermuer, 2011b; Smith, 2002). This emphasises the importance of the centralisation of SCI care to specialised SCI centres, which have improved access to critical services and expertise in surgical interventions and SCI rehabilitation.

In the care of SCI patients, the prevention and treatment of possible complications, such as pressure sores, respiratory problems and bladder dysfunction, play a critical role. High cervical injuries can lead to ventilatory dependence, and injuries lower than C5 can result in weakness of the accessory ventilatory muscles, compromising respiratory function (Hachem, Ahuja, & Fehlings, 2017). The management of secretions is of great importance to prevent pneumonia and atelectasis. Moreover, SCI patients are at risk for deep vein thrombosis and pulmonary embolus; thus, prophylaxis should be considered (Hachem et al., 2017). Neurogenic bladder dysfunction often results in catheter dependency and exposure to urinary tract infections (Hachem et al., 2017). The prevention of pressure ulcers should start immediately after the injury and should continue for the long term. Moreover, physical therapy after SCI traditionally includes range-of-motion and strengthening exercises, bed mobility and transfer exercises, and locomotor training (Hachem et al., 2017). Regardless of the aetiology, SCI patients benefit from inpatient rehabilitation (New et al., 2017). For example, in an Italian study, 25% of TSCI and NTSCI with AIS A, B or C at admission achieved an improvement of at least one AIS impairment level before discharge from inpatient rehabilitation (Scivoletto, Farchi, Laurenza, & Molinari, 2011).

In recent decades, the treatment of SCI has developed, and the development is anticipated to continue as there are numerous promising pharmacological and non-pharmacological treatments, both in terms of neuroprotection and neuroregeneration, in clinical trials (Ahuja et al., 2017).

2.2 Epidemiology of spinal fractures

2.2.1 Incidence

Depending on the study, spinal injuries make up 5–23% of all skeletal traumas (Liu et al., 2012; Pirouzmand, 2010; Somersalo et al., 2014). Generally, clear majority of traumatic spinal injury (TSI) patients sustain a TSF: Roche, Sloane and McCabe (2008) reported a proportion of 97%.

Related epidemiology studies have mainly focused on TSCI and osteoporotic spinal fractures; thus, there is only a limited number of studies about the incidence of TSFs covering the whole spine. A worldwide review article estimated a global incidence of 10.5/100,000 per year for TSI, meaning there are approximately 780,000 new cases per year in the world (Kumar et al., 2018). However, the most relevant available incidence figures have varied from 17–64/100,000 per year and are represented in Table 2. In Finland, the incidence of TSF requiring inpatient care has been reported to be 27/100,000 per year in Central Finland, which is in line with a recent paper from Iceland reporting an annual incidence of 31/100,000 (Kristinsdottir, Knutsdottir, Sigvaldason, Jonsson, & Ingvarsson, 2018; Somersalo et al., 2014). Other information covering the whole spine is not available from Nordic countries; however, the annual incidence of traumatic cervical fractures has been reported to be 12/100,000 in Norway (Fredo, Rizvi, Lied, Ronning, & Helseth, 2012).

2.2.2 Sex and age distribution

The mean age of TSF patients varies between 32 and 56 depending on the study (Kristinsdottir et al., 2018; B. Lenehan et al., 2009). Many studies have shown that the incidence of TSF increases with age, which is partly explained by the increasing role of osteoporosis (Hu et al., 1996; Kristinsdottir et al., 2018; Liu et al., 2018; Yang et al., 2008). For example, in Taiwan, the annual incidence of TSI steadily increased from 10/100,000 in the age group of 0–19 years to 435/100,000 in those over 80 years old (Yang et al., 2008). Some studies have also reported a peak frequency of TSFs in those aged 30 to 40 years old (Liu et al., 2012; Pirouzmand, 2010). In Iceland, however, the peak was found to be bimodal, peaking in those aged 21 to 30 and in those aged 81 to 90 years old (Kristinsdottir et al., 2018).

In general, the sex distribution in TSF patients is male dominated, as shown in Table 2. However, the sex distribution varies depending on the age group. In most studies, the distribution shifts to the majority of patients being female among the elderly, aged over 60 years (Hu et al., 1996; Roche et al., 2008; Yang et al., 2008). Osteoporosis is more prevalent in females, making them more vulnerable to TSFs due to low-energy trauma mechanisms such as low falls, which is a possible explanation for the phenomenon.

Table 2. The most relevant recent epidemiological studies reporting the incidence of traumatic spinal fracture/ traumatic spinal injury.

Country	Area	Study	Study design	Years	Patients (n)	Population of catchment area (n)	Incidence (/100.000/year)	Male (%)	Mean age (years)
Finland	Regional	Somersalo et al., 2014	Retrospective	2002–2008	381	250,000	27	-	49
Iceland	Nationwide	Kristinsdottir et al., 2018	Retrospective	2007–2011	487	315,000	31.0	56	56
Ireland	Regional	Roche et al., 2008	Retrospective	-	285	465,000	19.5	61	-
Canada	Regional	Hu et al., 1996	Retrospective	1981–1984	2063	1,081,000	64	52	
China	Nationwide	Liu et al., 2018	Retrospective	2014	168	512,000	32.8	55	55
United Arab Emirates	Regional	Grivna, Eid, & Abu-Zidan, 2015	Prospective	2003–2006	239	-	17.4	90	38
Taiwan	Nationwide	Yang et al., 2008	Retrospective	2000–2003	46 150	21,400,000	62.1	50	-

2.2.3 Aetiology

The majority of TSF results from road traffic accidents or falls. In most studies, these together cause approximately 90% of such injuries, but the proportions and the leading causes vary depending on the country and the study (Grivna et al., 2015; Hu et al., 1996; Kristinsdottir et al., 2018; Leucht et al., 2009; Liu et al., 2018; Roche et al., 2008; Tee, Chan, Fitzgerald, Liew, & Rosenfeld, 2013; Wang et al., 2012). In studies from Australia, the United Arab Emirates and Ireland, road traffic accidents have been the leading cause, with proportions of 45%, 48%, and 34–42%, respectively (Grivna et al., 2015; Lenehan et al., 2009; Roche et al., 2008; Tee et al., 2013). High falls, in contrast, were found to be the leading cause in a German study, causing 39% of such fractures, while low falls were the main cause in Iceland, at 33%, in the Netherlands, at 36%, and in China, at 32–72%, depending on age group and gender (den Ouden et al., 2019; Kristinsdottir et al., 2018; Leucht et al., 2009; Liu et al., 2018). Sports and violence are less frequent causes. In Irish and Icelandic populations, TSFs were caused by sports in 11–12% of cases, with equestrian sports being the leading cause of sports-related TSF in both studies (Kristinsdottir et al., 2018; Lenehan et al., 2009).

Regardless of the study, the aetiology distribution varies between different age groups. High-energy mechanisms, especially road traffic accidents, are the most important mechanism in younger age groups, whereas low falls cause the majority of TSFs in the elderly (den Ouden et al., 2019; Hu et al., 1996; Kristinsdottir et al., 2018; Liu et al., 2018; Roche et al., 2008). This is seen also in the mean age of study populations with different leading trauma mechanisms: the mean ages in a German study with high fall as the leading cause and in a study from the United Arab Emirates with road traffic accidents as the leading cause were 44 and 38 years, respectively, whereas in the Icelandic and Chinese populations, which both featured low falls as the main trauma mechanism, the mean ages were 56 and 55 years, respectively (Grivna et al., 2015; Kristinsdottir et al., 2018; Leucht et al., 2009; Liu et al., 2018).

2.2.4 Fracture level and classification

Most fractures occur in the thoracolumbar spine, especially in the junction (Th11–L2) (Hu et al., 1996; Kristinsdottir et al., 2018; Leucht et al., 2009; Liu et al., 2018; Tee et al., 2013; Wang et al., 2012). The first lumbar vertebra seems to be the most commonly fractured vertebra, followed by the other vertebrae of the thoracolumbar junction. The fractures of thoracic vertebrae outside the thoracolumbar junction (Th1–Th10) are not so common as are fractures of the second and fifth to seventh cervical vertebrae, in which the majority of the cervical fractures occur (Leucht et al., 2009; Roche et al., 2008).

In the majority of fractures, the body of the vertebra is fractured. The second cervical vertebra (axis), due to its unique anatomy, is an exception, with the odontoid process being the most common location of the fracture (Roche et al., 2008; Tee et al., 2013). Leucht et al. (2009) graded spinal fractures according to the AO classification (C1–C2 not included): the majority of 55% had a type A fracture (compression), 17% had a type B fracture (distraction) and 19% had a type C fracture (rotational dislocation). The majority of type A fractures were found in the thoracolumbar junction, whereas type B fractures occurred more commonly in the cervical spine. Moreover, the authors found a correlation between trauma mechanism and fracture level and classification. Fractures due to low or high falls tended to occur in the thoracolumbar junction, while those due to road traffic accidents occurred in the cervical and thoracic spine. The explanation may partly relate to the biomechanics of the spine: the cervicothoracic junction has relatively little muscular support, making it vulnerable to accelerative and decelerative forces, whereas the thoracolumbar junction has strong muscular support, protecting against distraction forces, but has greater weight on each vertebral body, making it more vulnerable to compression fractures (Leucht et al., 2009). The majority of type A fractures were caused by falls, whereas traffic accidents and falls from great heights caused type B fractures. Type C fractures were predominantly caused by road traffic accidents.

2.2.5 Associated injuries

Traumatic spinal cord injuries

Depending on the study, TSFs are associated with SCI in 9–44% of cases (den Ouden et al., 2019; Fletcher et al., 1995; Hu et al., 1996; Kristinsdottir et al., 2018; Leucht et al., 2009; Oliver et al., 2012; Wang et al., 2012). NTSCIs seem to be more common than TSCIs (New & Sundararajan, 2008). The incidence of TSCI has varied from 5.9–97.0/1,000,000 per year in studies published during the last decade (Ahoniemi et al., 2011; Bjornshave Noe, Mikkelsen, Hansen, Thygesen, & Hagen, 2015; Couris et al., 2010; Divanoglou & Levi, 2009; Ferro et al., 2017; Hagen, Lie, Rekand, Gilhus, & Gronning, 2010; Halvorsen et al., 2019a; Jain et al., 2015; Joseph et al., 2015; Joseph et al., 2017; Koskinen et al., 2014; Kristinsdottir et al., 2018; Kriz, Kulakovska, Davidova, Silova, & Kobesova, 2017; Kudo et al., 2019; Lenehan et al., 2012; Li et al., 2011; Lofvenmark et al., 2015; Majdan, Brazinova, & Mauritz, 2016; Mirzaeva, Gilhus, Lobzin, & Rekand, 2019; Montoto-Marques et al., 2017; New, Baxter, Farry, & Noonan, 2015; Ning et al., 2011; Sabre et al., 2015). In Finland, the incidence of TSCI has been reported to be 25.1–38.1/1,000,000 per year at the Oulu UH and Tampere UH SCI responsibility areas in 2012, which was higher than the previously reported average of 13.8/1,000,000 between 1976 and 2005 (Ahoniemi et al., 2011; Koskinen et al., 2014).

Cervical-level fractures are associated with SCI more often than are thoracic or lumbar fractures (den Ouden et al., 2019; Kristinsdottir et al., 2018; Leucht et al., 2009). The proportion of cervical injuries among all TSCIs has varied from 49–72%, meaning, naturally, that TSCI causes tetraplegia more often than it causes paraplegia (Hagen, Eide, Rekand, Gilhus, & Gronning, 2010; Halvorsen et al., 2019a; Joseph et al., 2015; Mirzaeva et al., 2019; Ning et al., 2011). The majority of such injuries are incomplete, with the frequency of complete AIS A injuries varying from 17–39%, depending on the study (Ferro et al., 2017; Hagen et al., 2010a; Joseph et al., 2015; Koskinen et al., 2014; Kristinfsdottir et al., 2018; Mirzaeva et al., 2019; Ning et al., 2011). In the last few decades, the frequency of cervical injuries, especially high cervical (C1–C4) injuries, has increased, while that of complete injuries has decreased, and this has also been seen in Finland (Ahoniemi, Alaranta, Hokkinen, Valtonen, & Kautiainen, 2008; Chen, He, & DeVivo, 2016). In the future, this trend has been anticipated to continue (Devivo, 2012).

Naturally, the most common trauma mechanisms of TSCI are similar to those of TSF: falls and road traffic accidents. The aetiologies seem to vary between different countries. While road traffic accidents remain common worldwide, high rates of falls has been reported especially in Western Europe, and the proportion of violence is higher in North America compared to other regions (Lee, Cripps, Fitzharris, & Wing, 2014). In Finland, falls seems to be the most common aetiology for TSCI, as proportions of 41% and 65% have been reported, and this trend has also been revealed in other Nordic countries (including Sweden, Norway and Iceland; Ahoniemi et al., 2008; Divanoglou & Levi, 2009; Hagen et al., 2010a; Conran Joseph et al., 2017; Koskinen et al., 2014; Kristinsdottir et al., 2018). The age distribution in different trauma mechanisms follows that of TSFs, for which falls, especially low falls, are the leading cause in the elderly and road traffic accidents are the leading cause in younger age groups (Ferro et al., 2017; Halvorsen et al., 2019a; Koskinen et al., 2014; Lenehan et al., 2012). Many studies have shown an increasing proportion of fall-related SCIs in recent decades, and simultaneously, the mean age of TSCI patients has increased and the proportion of road traffic injuries has decreased in most studies (Ahoniemi et al., 2008; Bjornshave Noe et al., 2015; Chen et al., 2016; Hagen et al., 2010a; Jain et al., 2015; Kriz et al., 2017; Montoto-Marques et al., 2017).

Non-spinal associated injuries

In addition to SCIs, spinal fractures are also often associated with non-spinal injuries. Non-spinal ASOIs have been reported to be present in 30–73% of TSF patients (den Ouden et al., 2019; Hu et al., 1996; Leucht et al., 2009; Wang et al., 2012). In a level-one trauma centre study population (Netherlands), the mean Injury Severity Score (ISS) for all TSF patients was 17 ± 12 (a patient with an ISS of ≥ 16 was considered a polytrauma patient; den Ouden et al., 2019). Thoracic fractures were associated with the highest ISS, followed by cervical fractures. High-energy trauma mechanisms such as road traffic injuries or high falls increase the likelihood of ASOIs (Leucht et al., 2009). For example, Hu et al. (1996) reported that 46% of TSF patients with a high-energy trauma mechanism had an ASOI, compared to 21% of those with low fall as the trauma mechanism.

In Table 3, incidences of ASOIs in different anatomic regions are seen. Injuries to the head, thorax and extremities seem to be common among TSF patients, while the incidence of abdominal injuries is lower. Head injuries are especially common among those with cervical injuries, as up to a 48% incidence has been reported (den Ouden et al., 2019; Hu et al., 1996). Hu et al. (1996) found that head injuries were also common in conjunction with thoracic injuries, with extremity injuries being more common compared to cervical injuries. In lumbar fractures, in contrast, head injuries were less frequent, while extremity injuries were even more common than they were with thoracic injuries. A high incidence of associated thoracic injuries in thoracic fractures (31%) and lumbar fractures (22%) was also reported by den Ouden et al. (2019).

In a German study population, head and thoracic injuries were more frequent in road traffic accidents, whereas pelvic injuries were overrepresented in falls (Leucht et al., 2009). A similar finding was reported in a Chinese study concerning head injuries: they reported a lower frequency of extremity injuries in road traffic injuries, suggesting that the underlying reason for this may be the protective nature of the car cage (Wang et al., 2012).

Table 3. Incidence of associated injuries among traumatic spinal fracture patients in different studies.

Study (n)	SCI	Non-spinal ASOI				
	Total	Total¹	Head	Thorax	Abdomen	Extremity
den Ouden et al., 2019 (n = 1479)	9%	73%	26%	24%	7%	32%
Wang et al., 2012 (n = 3142)	44%	30%	6%	12%	0.5%	12%
Oliver et al., 2012 (n = 2562)²	22%	-	33%	35%	22%	19%
Leucht et al., 2009 (n = 562)	25%	54%	19%	19%	3%	26%
Hu et al., 1996 (n = 944)	13%	38%	14%	9%	6%	20%

¹TSF patients with at least one ASOI; ²Only severe injuries were included (Abbreviated Injury Scale ≥ 3); NA = not applicable

2.2.6 Survival and causes of death

The in-hospital mortality of TSF patients has varied between 0.1% and 6.1% according to different studies (Hu et al., 1996; Kattail et al., 2009; Wang et al., 2012; Westerveld, van Bemmel, Dhert, Oner, & Verlaan, 2014; Williams et al., 2014). Mitchell et al. (2018) reported a 90-day mortality of 7% among those aged 64 years or under, 12% among those 65 to 74 years old, 30% among those 75 to 84 years old and 51% among those over 85 years old. They discovered that those who had comorbid conditions, had serious injury or were injured at home or in an aged care facility were at an increased risk of death (Mitchell et al., 2018). Westerveld et al. (2014), however, found that the risk for death in hospitalised TSF patients over 50 years old increased with increasing age, neurological deficit (AIS A) and presence of diffuse idiopathic skeletal hyperostosis (DISH). Polytrauma patients have also been revealed to have an increased risk of short-term mortality (Hebert & Burnham, 2000).

Data related to long-term mortality after TSF is scarce. Most studies deal with osteoporotic spinal fractures, and the mortality after these has been reported to be elevated compared to the general population, both in clinical and incidental vertebral fractures (Bliuc et al., 2009; Hasserius, Karlsson, Nilsson, Redlund-Johnell, & Johnell, 2003; Kado et al., 2003). Concerning thoracolumbar TSFs in those over 50 years old, a 2-year SMR and 2-year mortality rate of 2.5 and 21%, respectively, in males and 1.9 and 10%, respectively, in females have been reported in South Korea (Lee et al., 2012). Bliuc et al. (2009) reported that mortality after clinical or incidental osteoporotic spinal fracture in those over 60 years old remained higher compared to the general population for 5 years after the injury, but after that, the mortality rates did not differ from the age-matched general population. For the first 5 years, the SMRs were 1.8 for males and 2.3 for females, in total. The age group of 60- to 74-year-olds had higher SMRs—at 3.8 and 4.2 in males and females, respectively—than did those over 75—at 1.5 in males and 1.9 females (Bliuc et al., 2009).

The data about the causes of death after TSF is also limited. It seems that respiratory-related causes of death are remarkable after spinal fracture. Westerveld et al. (2014) reported that the main cause of in-hospital deaths was respiratory failure (Westerveld et al., 2014). In a Singaporean study of a geriatric study population of those over 80 years old with osteoporotic compression fractures, the leading causes for death at 3, 6 and 12 months after the injury were, at all time points, pneumonia and ischemic heart disease (Soon et al., 2019). A decrease in respiratory function among high TSCI patients is evident, but vertebral compression fractures are also known to affect negatively to respiratory function, probably through increased kyphosis of the spine (Harrison, Siminoski, Vethanayagam, & Majumdar, 2007). The increased risk for pneumonia after thoracic compression fracture has also been proven, both in the short and long term (Kim et al., 2018). The authors suggested several reasons for this, including the decrease in respiratory function, restriction of active cough due to pain, immobilisation and decreased overall physical performance in the long term.

2.3 Epidemiology of acquired non-traumatic spinal cord injury

2.3.1 Incidence

There is only a limited number of epidemiological studies about NTSCI, and consequently, the incidence data also remains insufficient in many regions. In a global review, the incidence of NTSCI ranged from 2–80/1,000,000 per year, with studies varying in quality (New et al., 2014). The lowest median annual incidence was found in Western Europe (6/1,000,000) and the highest in North America (76/1,000,000). The authors did not find an explanation for the exceptionally low incidence in Western Europe compared to other developed countries. The 8 Western European studies included were relatively old, with the most recent being published more than 15 years ago (Ronen et al., 2004). A similar incidence was, however, found in a recent SCI registry-based study from Norway: 7.7–10.4/1,000,000 (Halvorsen et al., 2019b). The most relevant studies from the last decade reporting the incidence of NTSCI are shown in Table 4. Despite the fact that NTSCIs seem to be more common than TSCIs, there is clearly less epidemiological data available about NTSCIs (New & Sundararajan, 2008).

It has been reported that half of the causes of NTSCI are age-related and, as there is also a worldwide trend of aging in the population, the incidence of NTSCI is anticipated to grow during the coming decades (New, Rawicki, & Bailey, 2002; New & Sundararajan, 2008).

2.3.2 Sex and age distribution

The sex distribution among NTSCI patients is, according to most studies, slightly male-dominated (Halvorsen et al., 2019b). Compared to TSCI, however, the proportion of females is higher (Halvorsen et al., 2019b; New, Simmonds, & Stevermuer, 2011a).

The mean age of NTSCI patients in most studies is 55–65 years, which is higher than that among TSCI patients (Fortin, Voth, Jaglal, & Craven, 2015; Guilcher et al., 2010; Halvorsen et al., 2019b; New et al., 2016; Ronen et al., 2004; van den Berg, Castellote, Mahillo-Fernandez, & de Pedro-Cuesta, 2012). The incidence seems to grow with age in both males and females, with the highest peak occurring at 60–70 years (Halvorsen et al., 2019b; van den Berg et al., 2012). In a Spanish study, van den Berg et al. (2012) showed that the mean age has been growing over the decades, being 40 in the 1970s and 60 in 2000s. They also reported that the proportion of NTSCI cases after the age of 60 rose from 24% to 57% during the same period.

2.3.3 Aetiology

International SCI data sets for NTSCI were published in 2014 and included a consensus classification for aetiologies (New & Marshall, 2014). Prior to that, an international classification did not exist, and the aetiology classification varied between different studies. According to the international data sets, hierarchical classification aetiologies of NTSCI are divided to congenital, genetic and acquired injuries. The aetiology classification is seen in Table 5.

Globally, it is known that developed countries tend to have a higher frequency of NTSCI caused by degenerative disorders and tumours, whereas developing countries have higher proportions of infections, especially tuberculosis and human immunodeficiency virus (HIV), although tumours have also been reported to be common (New et al., 2014). The most relevant and up-to-date international data about the aetiology distribution of NTSCI comes from a multicentre study including inpatient-rehabilitated NTSCI patients from nine SCI centres from different countries (New et al., 2016). They reported degenerative diseases to be the most common aetiology, with a 31% proportion, followed by vascular diseases with 20%, malignant neoplasms with 16%, benign neoplasms with 9%, infectious causes with 13% and other causes with 11% proportions. It must be stated that the aetiology distribution varied between different countries, and the authors pointed out that further studies are needed to separate centre effects from country effects. The study also reported major differences between the aetiology groups, highlighting how diverse the NTSCI patient group is. Patients with infection or benign neoplasm as the aetiology were younger, and only benign tumour patients were more commonly females than males. Degenerative disorders, infections and benign tumours caused tetraplegia more often than did other aetiologies, whereas vascular and malignant aetiologies had higher proportions of paraplegia. Vascular and infection groups tended to be more severe according to AIS classification. These patients also had a more acute onset than did patients with other aetiologies.

In a Spanish retrospective study from 1972–2008, an increasing incidence of vascular causes, tumours and degenerative diseases was reported, whereas the frequency of NTSCI caused by infection decreased (van den Berg et al., 2012).

Table 4. The most relevant recent epidemiological studies reporting the incidence of non-traumatic spinal cord injury.

Country	Area	Study	Study design	Years	Patients (n)	Population of catchment area (n)	Incidence (/1,000,000/ year)	Male (%)	Mean age (years)
Norway	Nationwide	Halvorsen et al., 2019b	Retrospective	2012–2016	225	5,260,000	7.7–10.4	59	55
Czech Republic	Nationwide	Kriz et al., 2017	Prospective (degenerative excluded)	2006–2015	906	10,500,000	8.6	-	-
Spain	Regional	van den Berg et al., 2012	Retrospective	1972–2008	541	1,201,230	12.1	53	52
Canada	Nationwide	Noonan et al., 2012	Retrospective	2010	-	-	68	-	-
Canada	Nationwide	Guilcher et al., 2017	Retrospective	2004–2011	6362	27,401,648	33.2	57	60
Australia	Regional	New & Sundararajan, 2008	Retrospective	2000–2006	631	3,959,000	26	-	-

Table 5. Hierarchical aetiology classification of non-traumatic spinal cord injuries. Modified from international spinal cord injury data sets for non-traumatic spinal cord injuries (New & Marshall, 2014).

Aetiology	Example of condition
Acquired	
Vertebral column degenerative disorders	Spinal stenosis, disc prolapse
Vascular disease	Epidural haematoma, aortic dissection
Benign neoplasms	Intradural (e.g., meningioma), intramedullary (e.g., benign astrocytoma, ependymoma)
Malignant neoplasms	Metastasis, haematological (e.g., myeloma), neural (e.g., malignant astrocytoma), vertebral (e.g., osteosarcoma)
Metabolic disorders	Osteoporosis, deficiencies (e.g., vitamin B12, folate)
Infection	Bacterial extradural abscesses, viral infections (e.g., herpes group)
Inflammatory and autoimmune diseases	Multiple sclerosis, ankylosing spondylitis
Toxin related	Pharmacological agents
Radiation related	Radiation myelitis
Miscellaneous	Amyotrophic lateral sclerosis, syringomyelia
Congenital	Spina bifida occulta, myelomeningocele, Arnold–Chiari malformation
Genetic disorders	Hereditary spastic paraplegia, spinocerebellar ataxias

2.3.4 Severity of injury

NTSCI results in tetraplegia in approximately 30% and paraplegia in 70% of the cases, most of the injuries being incomplete (Halvorsen et al., 2019a; New et al., 2011a; van den Berg, Castellote, de Pedro-Cuesta, & Mahillo-Fernandez, 2010). A major proportion of NTSCIs occur in the thoracic spine (Catz et al., 2004; Scivoletto et al., 2011). The neurological level of injury varies between different aetiologies, with the majority of cervical injuries being due to spinal stenosis, of thoracic injuries being due to vascular disorders, infections and tumours, and of lumbar injuries being due to disc prolapses (Catz et al., 2004). In most studies, more than half of NTSCIs are classified as AIS D (Catz et al., 2004; Halvorsen et al., 2019a; Scivoletto et al., 2011; van den Berg et al., 2012). Generally, NTSCI patients' neurological impairment is less severe and they have a higher Functional Independence Measure (FIM) motor subscale score, compared to TSCI patients (Halvorsen et al., 2019b; New et al., 2011a).

Most NTSCI have significant improvement in functional capacity and neurological impairment during rehabilitation (New et al., 2017). However, New et al. (2017) pointed out in their systematic review that the diversity of aetiologies makes the prediction of neurological improvement and rehabilitation outcomes challenging, as some of the causes of NTSCI are progressive (such as inoperable tumours, infections and some inflammatory diseases). In an international multicentre study, all but malignant aetiologies showed improvement in AIS classification during rehabilitation, with the highest improvement in vascular and infective aetiologies (New et al., 2016). Another study, however, found that patients with NTSCI due to malignant tumour made functional gains in inpatient rehabilitation and had an FIM improvement that was comparable to that of other NTSCIs (Fortin et al., 2015). Catz et al. (2004) reported that the odds for recovery according to AIS classification were highest for patients with aetiologies of benign tumours and degenerative diseases, and lowest for the aetiology of multiple sclerosis.

With adequate rehabilitation planning, and taking into account the clinical condition of the individual, the rehabilitation outcomes are usually remarkable. For example, patients with progressive disease such as malignant tumours can benefit from more short-term rehabilitation plans concentrating on vital functions such as bladder management and caretaker education (Buzzell et al., 2019).

2.3.5 Survival and causes of death

Survival after NTSCI is generally lower than that after TSCI (Hatch et al., 2017; van den Berg et al., 2010). However, there is only limited data available about the mortality and causes of death after NTSCI, while the subject has been extensively studied regarding TSCI. The diversity of aetiologies in NTSCI once again makes the prediction of survival challenging (New et al., 2017). However, mortality after NTSCI compared to that of the general population is elevated for all aetiologies (Buzzell et al., 2019). Malignant tumours have the worst prognosis of all the aetiologies, in general (van den Berg et al., 2010). It must also be noted that within the neoplasm group, the survival and prognosis in different subgroups vary depending on the tumour grade. As another example, intramedullary primary tumours such as gliomas and ependymomas often have very different outcomes than do extramedullary primary tumours such as meningiomas (Hatch et al., 2017).

In the US, Hatch et al. (2017) found that the mean survival after NTSCI was 6.8 (standard deviation [SD] = 0.3) years, and the estimated years of life lost

(EYOLL, compared to the control group) was 1.8 years, which was lower than that in the TSCI group (Hatch et al., 2017). The worst survival was found in NTSCI caused by metastatic cancer, with a mean survival length of 1.6 (SD = 0.7) years, in line with previous papers, and an EYOLL of 7.3 (SD = 0.7) years. Spinal cord ischaemia had the second most decreased survival, with a mean survival length of 5.5 (SD = 1.6) years and an EYOLL of 2.9 (SD = 1.6) years. The results showed significant variation between subgroups of vascular disorders, as the mean survival and EYOLL after NTSCI due to arteriovenous malformation were 8.0 (SD = 1.1) years and 0.3 (SD = 1.1) years, respectively, and after other vascular disorders were 7.7 (SD = 2.3) years and 1.1 (SD = 2.3) years, respectively. Infection, intramedullary and extramedullary tumours had only small decreases in mean survival after SCI (Hatch et al., 2017). They also found that, in addition to aetiology, increased age, male gender and lower functional status at discharge (FIM score) were independent predictors of decreased survival.

In Switzerland, the risk for death was found to be 1.6 times higher after non-malignant NTSCI than it was in the general population (based on SMR, 1990–2011; Buzzell et al., 2019). When further divided into aetiology groups, the highest SMRs were 2.5 for the infection group and 1.7 for the vascular disorder group. The study did not report the SMR for malignant causes. However, in another study using the same study population, the malignant population had a significantly higher mortality: the hazards ratio (HR) for death was 6 for the malignant group, with degenerative diseases as the reference group, while the HRs in other groups varied between 0.9 and 1.4 (with the same reference group). Moreover, the survival rate after complete paraplegia due to malignant aetiology was 29% after 1 year and 9% after 5 years; this was lower than the survival rate after complete paraplegia due to non-malignant aetiology, which was 70% after 1 year and 46% after 5 years (Buzzell et al., 2019). They also found that age and completeness of injury were related to an increased risk for death in both non-malignant and malignant aetiologies, with age being a much more significant indicator in the non-malignant group. In non-malignant groups, males were also found to be at an increased risk for death. Neither the study of Buzzell et al. (2019) nor of Hatch et al. (2017) had data on the previous comorbid conditions of the patients.

There has only been one study about the causes of death after NTSCI, from Switzerland (Buzzell et al., 2019). The leading cause of death after NTSCI due non-malignant causes was cardiovascular diseases at a proportion of 40%, followed by neoplasms at 22% and digestive-related death causes at 6%. Respiratory infections accounted only for 4% of deaths, which was interesting, as they are the leading cause of death in many studies about TSCIs. Naturally, among NTSCIs due malignant neoplasm, the death cause was neoplasms in as much as 88% of cases. There was variability in the death causes among different non-malignant aetiologies. However, the highest risk of death compared to the general population (in terms of SMR) in all three of the biggest groups (i.e., degenerative, infection and vascular aetiologies) was infections (including respiratory infection, urinary infection, septicaemia or other infections). After NTSCI due to vascular disorder, the risk for cardiovascular diseases was higher than it was among other aetiologies, probably due to underlying health conditions (Buzzell et al., 2019).

3 Aims of the present study

The present study focuses on revealing the incidence, epidemiological characteristics and posttraumatic mortality of spinal injuries. The specific aims of the thesis according to the original publications are as follows:

I The first aim is to discover the epidemiological characteristics of TSI in Northern Finland. The most important variables include the incidence rate, level of the injury, age and sex distribution, aetiology, ASOIs and characteristics of treatment, such as length of stay (LOS) and need for surgical treatment or intensive care.

II The second aim is to clarify the long-term mortality and death causes after TSF in Northern Finland and to compare the mortality after TSF to the mortality of the general population. The aim is also to identify the patient groups at an increased risk of death.

III The third aim is to reveal the epidemiological characteristics of NTSCIs in Finland. The most important variables include the incidence rate, age and sex distribution, aetiology, classification of the injury and characteristics of treatment, such as the LOS and need for inpatient rehabilitation.

4 Materials and methods

4.1 Study design and approvals

Studies I and II are retrospective epidemiological studies based on the medical records of all TSI patients treated in Oulu UH, Oulu, Finland, from 2007–2011. Study III is a prospective epidemiological multicentre follow-up. The demographic data of patients with NTSCI were collected at Oulu UH and Tampere UH, Tampere, Finland, from 2012–2016.

Tampere UH and Oulu UH are the only tertiary-level centres in their own hospital districts offering spinal surgery, neurosurgery and intensive care. They are also tertiary-level referral centres for seven other central hospital districts (with Tampere UH having three and Oulu UH having four). In Studies I and II, Oulu UH's hospital districts covered a population of 737,680 in 2011 (14% of the population of Finland; Official Statistics of Finland, 2016). In 2011, the acute care, immediate rehabilitation and lifelong follow-up of SCI were centralised in three university hospitals (Tampere, Oulu, and Helsinki UH; Ministry of Social Affairs and Health, 2010). In Study III, Tampere UH and Oulu UH covered a population of 3,073,052 in 2013 in terms of SCI care (56.4% of the population of Finland; Official Statistics of Finland, 2019).

4.2 Study sample and data collection

4.2.1 Study I and II

The study sample included TSI patients with an injury date from January 1, 2007, to December 31, 2011. Patient information was collected from the hospital care register, including all inpatient and outpatient visits and surgical procedures. Traumatic spinal column injuries and SCIs were identified using 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10) codes or Nordic Classification of Surgical Procedures (NCSP) codes (Table 6). The NCSP codes ranged from the closed reduction of a fracture of the spine (NAJ00) to the posterior reduction of a fracture of the lumbar spine (NAJ32).

Table 6. Diagnosis and procedure codes for subject inclusion in Study I and Study II.

ICD-10: Traumatic spine injuries	ICD-10: TSCIs	NCSP
S12.0-9	S14.0	NAJ00
S13.0-3	S14.1	NAJ10
S17.8-9	S24.0	NAJ12
S22.0-1	S24.1	NAJ20
S23.0-2	S34.0	NAJ22
S32.0-1	S34.1	NAJ30
S32.7-8	T09.3	NAJ32
S33.0-1	T91.3	NAJ99
M49.5*		

The process used to form the study samples is also shown in Figure 4. An automated search of ICD-10 and NCSP codes revealed 1,884 hits with admission dates from January 1, 2007 to April 31, 2012. An extended period was used in the automated search to identify patients with delayed referral. After the elimination of duplicates, 1,310 different patients were identified and reviewed to assess eligibility and collect data (e.g., patient and injury characteristics, ASOIs and LOS). During the review, we excluded patients who did not meet the inclusion criteria of traumatic injury (e.g., osteoporotic fractures without evident trauma) or injury date, providing a sample of 971 TSI patients for Study I. A total of 965 patients met the criteria for TSF (as 6 patients from the original study sample suffered a spinal dislocation without a fracture), and after excluding 18 foreign patients for whom mortality data was not available, a study sample of 947 TSF patients was formed for Study II.

Injury characteristics and aetiology were recorded according to ICD-10 external causes and grouped according to the International Spinal Cord Society (ISCoS) Core Data Set, modified to differentiate low falls (< 1 m) and high falls (> 1 m; DeVivo et al., 2006). Information about ASOIs was gathered according to ISCoS Core Data Set definitions. As a modification, the criteria for TBI were broadened to include cases with diagnostic findings in head CT or MRI scans and cases with moderate to severe TBI diagnosed after the initial trauma via neuropsychological testing. Times and causes of deaths were obtained from Statistics Finland's Archive of Death Certificates, and the annual population number, number of deaths, and death causes of the general population were obtained from Official Statistics of Finland (Official Statistics of Finland, 2016, 2018). The data acquisition started in January 2014. Times of deaths from Statistics Finland's Archive of Death Certificates were available until the end of 2016 and causes of deaths until the end of 2015, providing a minimum and maximum follow-up time of 5 and 9 years, respectively, for mortality and of 4 years for causes of death.

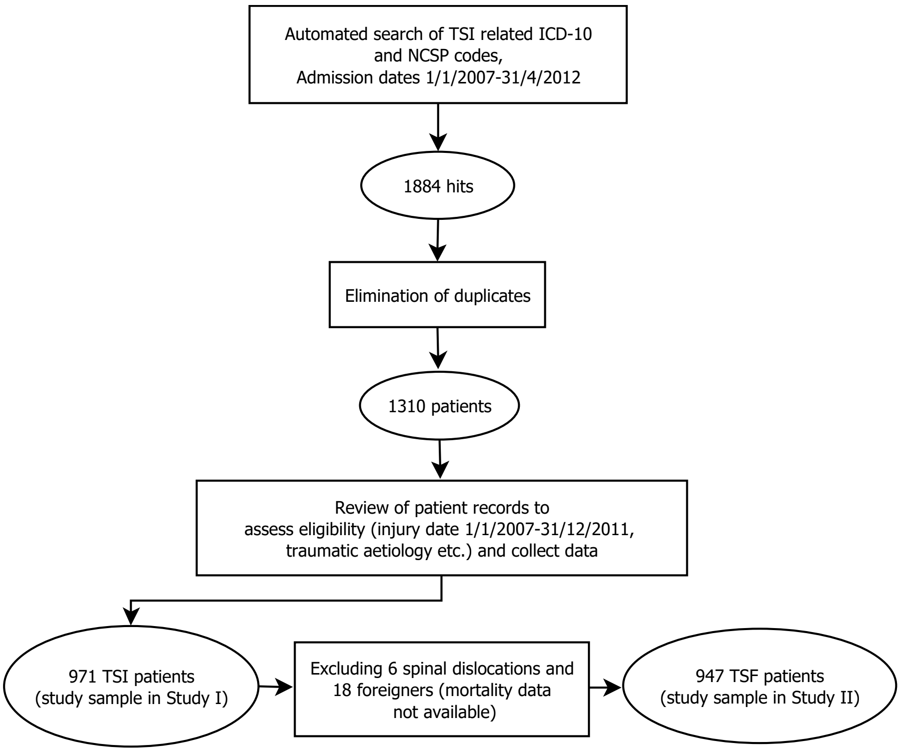

Fig. 4. Formation of the study samples in Study I and Study II.

4.2.2 Study III

The study sample for Study III included all newly diagnosed patients with acquired NTSCI admitted to Tampere UH from January 1, 2012, to December 31, 2015, and to Oulu UH from January 1, 2013, to December 31, 2016. Patients with progressive neurological diseases, such as multiple sclerosis or amyotrophic lateral sclerosis, were excluded from the study, as they are treated in neurology units in Finland. The care of congenital diseases, such as spina bifida, however, is centralised to paediatric units, and these cases were also excluded from the study.

In both SCI centres, an SCI rehabilitation team is informed when a patient with newly diagnosed SCI with neurological findings is admitted to the hospital. A specialist physician evaluates the patient in the acute phase and plans the rehabilitation with the support of the rehabilitation team. During the study period, a total of 430 patients met the inclusion criteria (Figure 5). The data was collected prospectively in the acute phase on the basis of the evaluation of the designated rehabilitation teams. ISCoS Core Data Set Version 1.1 was used to gather the data (DeVivo et al., 2006). The aetiology of NTSCI was retrospectively classified and grouped according to ISCoS Core Data Set Version 2.0 based on a similar in-house classification modified from the International NTSCI Data Set and ICD-10 codes (Biering-Sorensen et al., 2017; New & Marshall, 2014). The severity of injury and neurological level were classified according to the ISNCSCI (Kirshblum et al., 2011). These were categorised according to recommendations by DeVivo, Biering-Sorensen, New and Chen (2011). The LOS was calculated as the number of days from acute care admission to final discharge from spinal cord–specific rehabilitation, including all inpatient days in specialised health care but not possible days in home or primary health care. The annual population number was obtained from Official Statistics of Finland (Official Statistics of Finland, 2019).

4.3 Statistical methods

In Study I, the incidence data was divided according to catchment area, while other data was reported covering the whole Northern Finland sample. The annual population number was used to assess incidence rates.

In Study II, the observed deaths during the first year after a fracture were used in the calculation of SMRs. Expected deaths were calculated using the average one-year mortality according to gender and age group in the general population of Northern Finland from 2007–2011. SMRs were calculated for the complete sample and for different age groups. To minimise the effect of difference in the age distribution of the general population and the study sample, the SMR of the oldest age group of those over 65 years old was age-adjusted, dividing it into groups of those aged 65–74 years, 75–84 years and over 85 years old.

As the treatment of SCIs is centralised in Finland, Tampere UH and Oulu UH are also responsible for the treatment of other UHs' SCI patients. In Study III, to report the incidence rate as accurately as possible, these were calculated using the population of Tampere UH's and Oulu UH's primary referral areas for SCI care (1,853,437 in 2015). Thus, only the patients whose residency was in these 7 hospital districts were included in the calculation of incidence rate (410 patients). Other data were reported using the whole study sample. The incidence during the study period was calculated by dividing the number of NTSCI patients by the sum of each year's population in the study period, providing the yearly incidence rate. Incidence rates were also reported separately for each year.

The $\chi 2$ and the Fisher's exact tests were used for analysing group differences in categorical variables, and the Student's t-test, the Mann–Whitney U test and the Kruskal–Wallis test (Study III) were used to analyse group differences in continuous variables. Logistic regressions were used to determine odds ratios (ORs; Study I). The Kaplan–Meier curves were used to determine survival ratios, and the Cox proportional hazards regression models, using the forward stepwise method, were used to determine the HRs (Study II). A p-value of ≤ 0.05 was considered statistically significant. IBM SPSS Statistics versions 22, 23 and 25 (IBM, Armonk, NY, USA) were used to perform the statistical analyses.

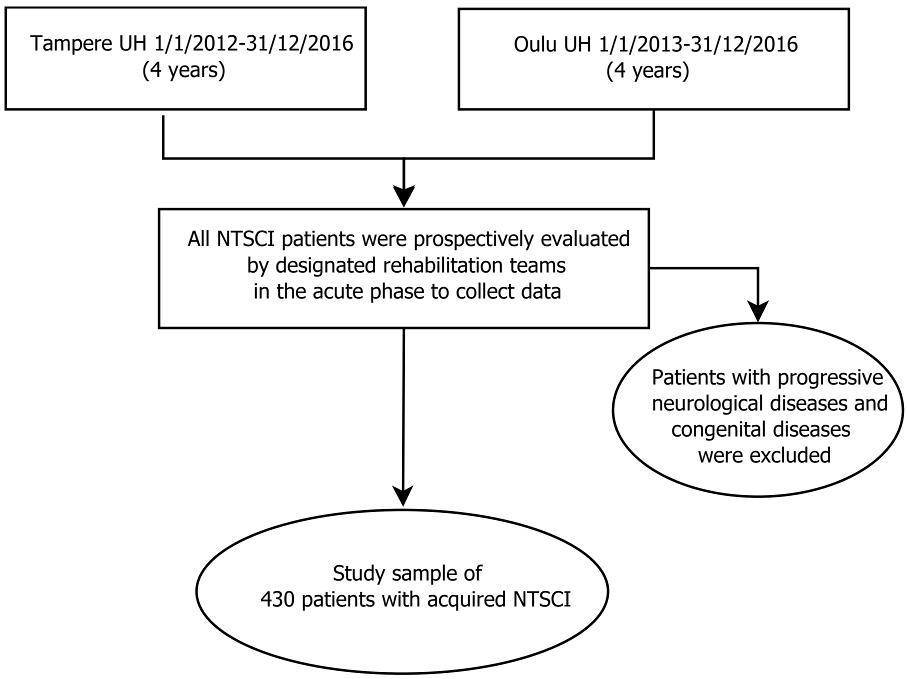

Fig. 5. Formation of the study sample in Study III.

4.4 Ethics and approvals

Study approvals were obtained from Oulu UH administration (Study I, II and III) and Tampere UH administration (Study III). In Study I and Study II, ethics committee approval was not needed, as these studies were based on hospital registers. As the data collection in Study III was done during the standard practice, ethics committee approval was not needed.

5 Results

5.1 Epidemiology of traumatic spinal injuries (Study I)

5.1.1 Incidence

During the 5-year period of 2007–2011, 971 patients with TSI were admitted to Oulu UH. In total, 965 patients (99.4%) were diagnosed with a spinal fracture, while the remaining 6 patients (0.6%) had a TSCI without a fracture. A total of 101 patients (10.4%) suffered an SCI. The incidence of TSI requiring hospital care was 34.8/100,000 per year in the hospital district of Oulu UH and 26.3/100,000 per year in Northern Finland, as treated in Oulu UH. The incidence of TSI requiring surgical intervention was 9.7/100,000 per year in the hospital district of Oulu UH and 10.3/100,000 per year in Northern Finland. The overall characteristics of the study population are shown in Table 7.

5.1.2 Age and gender

TSI was more common in males (n = 581; 59.8%) than it was in females (n = 390; 40.2%). The mean age of the patients was 53.1 years. Men were significantly younger (50.3 years) than were women (57.6 years; $p < 0.001$). The age distribution is represented in Figure 6.

5.1.3 Aetiology and trauma mechanism

Low falls (< 1 m) were the most common aetiology (35.8%), followed by road traffic accidents (29.7%) and high falls (> 1 m; 21.9%; Table 8). In males, road traffic accidents were the leading cause of injury (33.0%), followed by high falls (27.7%). In females, low falls were the most common aetiology (49.0%), followed by road traffic accidents (24.0%). There were 91 (9.4%) work-related injuries.

In age groups under 45 years old, road traffic accidents caused 48.1% of the injuries, while in age groups over 60 years old, low falls accounted for 63.7% of the injuries. In age group of 45–59 years old, the aetiology was more equally distributed, as high falls accounted for 30.8%, low falls for 28.1% and road traffic accidents for 27.1% of the injuries.

Table 7. Patient characteristics in Study I.

Characteristic	TSI 2007–2011
Number of cases	971
Incidence per year/100,000	27.4–40.7
Gender (male/female)	581/390
Age; mean ± SD	53.1 ± 21.9
Invasive treatment; n (%)	416 (42.8%)
Spinal surgery	376 (38.7%)
Vertebro-/kyphoplasty	40 (4.1%)
Level of injury; n (%)	
Cervical	283 (29.1%)
Thoracic	180 (18.5%)
Lumbar	323 (33.3%)
Sacrum	63 (6.5%)
Cervical + Thoracic	41 (4.2%)
Cervical + Lumbar	5 (0.5%)
Thoracic + Lumbar	65 (6.7%)
Cervical + Thoracic + Lumbar	5 (0.5%)
Need for ICU treatment; n (%)	149 (15.3%)
SCI; n (%)	101 (10.4%)
ASOI (non-spinal); n (%)	238 (24.5%)
Brain injury	71 (7.3%)
Thoracic injury	58 (6.0%)
Intra-abdominal injury	20 (2.1%)
Limb fracture	88 (9.0%)
Other	116 (11.9%)

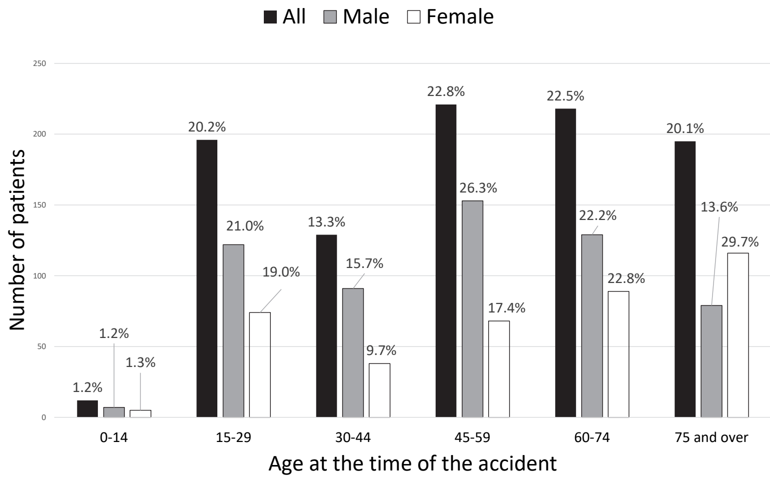

Fig. 6. Age distribution in traumatic spinal injury patients overall and according to gender.

Table 8. Aetiology of traumatic spinal injuries.

Mechanism of injury	Patients (%)	Male (%)	Female (%)	Age (years, mean ± SD)
Low fall (< 1 m)	348 (35.8%)	157 (27.0%)	191 (49.0%)	69.3 ± 15.5
Road traffic accident	288 (29.7%)	192 (33.0%)	96 (24.6%)	42.5 ± 20.1
High fall (> 1 m)	213 (21.9%)	161 (27.7%)	52 (13.3%)	47.5 ± 19.0
Sports	68 (7.0%)	35 (6.0%)	33 (8.5%)	34.3 ± 16.6
Violence	13 (1.3%)	8 (1.4%)	5 (1.3%)	45.4 ± 14.2
Other	37 (3.8%)	26 (4.5%)	11 (2.8%)	52.0 ± 17.7
Unknown	4 (0.4%)	2 (0.3%)	2 (0.5%)	56.0 ± 24.3

5.1.4 Level of injury and associated injuries

Lumbar spine fractures comprised one-third of the injuries, being the most common site of injury (33.3%; Figure 7). Single vertebra fracture was found in 592 patients (61.0%), while 379 patients (39.0%) had multiple vertebrae fractures. The frequency of cervical spinal injuries was significantly higher in males (n = 229; 39.4%) than it was in females (n = 101; 25.9%; $p < 0.001$), while isolated sacral fractures were more common in females (n = 42; 10.8%) than they were in males (n = 21; 3.6%; $p < 0.001$). The first lumbar vertebra was the most commonly fractured vertebra, with 228 fractures, followed by the sixth cervical vertebra, with

128 fractures (Figure 7). The thoracolumbar junction (Th11–L2) was fractured in 43.2% of patients (n = 419).

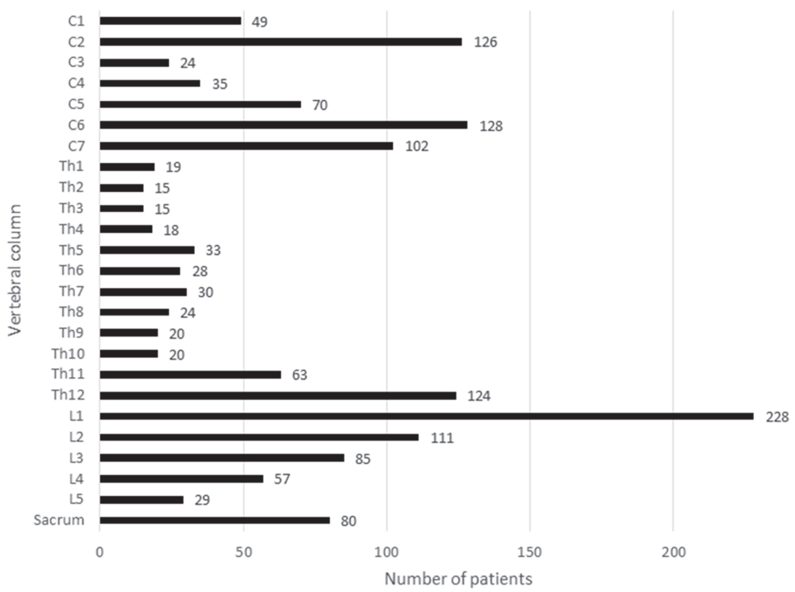

Fig. 7. The distribution of injured spinal columns and the number of patients injured in each column.

In total, 309 patients (31.7%) had at least one ASOI (SCI or non-spinal ASOI), and 90 patients (9.3%) had more than one ASOI. ASOIs were more prevalent in males (n = 210; 36.1%) compared to females (n = 99; 25.4%; $p < 0.001$). In addition, 101 patients suffered an SCI (10.4%), of whom 81.2% were male (n = 82; 14.1% of all males) and 18.8% were female (n = 19; 4.9% of all females; $p < 0.001$). Co-existing TBI was found in 71 (7.3%) patients. The frequencies of other ASOIs are shown in Table 7. ASOIs were most prevalent in road traffic injuries, as 42.0% of such cases (n = 121) were associated with other injuries. In contrast, spinal injuries caused by low falls were associated with other traumatic injuries in only 22.1% of such cases (n = 77; $p < 0.001$). The frequency of non-spinal ASOIs and SCIs in different trauma mechanisms are shown in Figure 8. Patients with SCI caused by low falls were older (71.0 years vs 43.7 years; $p < 0.001$) and more often had cervical injury (66.7% vs 41.9%; $p = 0.015$) when compared to patients with SCI caused by other aetiologies. The factors associated with ASOI, SCI and TBI are presented in Table 9.

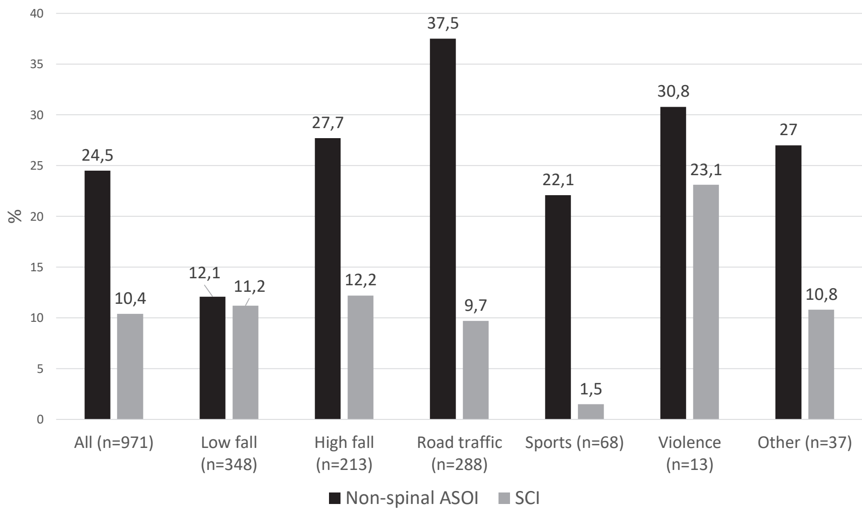

Fig. 8. Frequency of non-spinal associated injuries and spinal cord injuries among traumatic spinal injury patients with different trauma mechanisms.

5.1.5 Hospital care

Most of the patients with TSI were instantly hospitalised. The median LOS was 5 days (range: 1–273 days). If TSI was accompanied by an ASOI, this lengthened the hospital stay (9 days vs 4 days; $p < 0.001$). Patients who were operated on had a longer LOS than did conservatively treated patients (8 days vs 3 days; $p < 0.001$). Intensive care was needed in the treatment of 149 patients (15.3%) with a median duration of 4 days (range: 1–53 days). ASOI was closely related to the need for intensive care, as 36.2% of patients with an ASOI required it compared to 5.4% of patients without an ASOI ($p < 0.001$). The frequency of spinal surgery was 38.7% (n = 376) in the whole study population. Spinal surgery was also common among patients in the low-fall group, as 37.9% of them were operated on (n = 132). The median time from injury to surgery was 4 days (range: 0–673) and from hospitalisation to surgery was 2 days (range: 0–184). Open surgery using the posterior approach was the most common (n = 234; 62.2%). The anterior approach was used in 128 cases (34.0%), including in 107 (47.1%) cases in the cervical area. Combined anterior and posterior operation was used in 14 (3.7%) cases.

Table 9. Odds ratios (OR) (95% confidence interval [CI]) of associated injuries, brain injuries and spinal cord injuries.

Injury	OR	95% CI	p-value
ASOI			
Mechanism of injury			
Low fall (n = 347)	1		
Road traffic accident (n = 288)	2.9	2.0–4.1	< 0.01
High fall (n = 209)	2.6	1.7–3.9	< 0.01
Highest fractured level			
Lumbar (n = 324)	1		
Cervical (n = 330)	2.1	1.5–3.0	< 0.01
Sacral (n = 63)	4.9	2.8–8.9	< 0.01
Brain injury			
Mechanism of injury			
Low fall (n = 347)	1		
Road traffic accident (n = 288)	8.0	3.5–18.3	< 0.01
High fall (n = 209)	6.5	2.6–16.3	< 0.01
Violence, other or unknown (n = 53)	4.1	1.2–14.7	0.03
Highest fractured level			
Lumbar (n = 324)	1		
Cervical (n = 330)	3.6	1.8–7.1	< 0.01
Sacral (n = 63)	4.1	1.5–11.0	< 0.01
SCI			
Males (n = 575)	2.7	1.6–5.0	< 0.01
Mechanism of injury			
Low fall (n = 347)	1		
Sports (n = 68)	0.1	0.01–0.9	0.04
Highest fractured level			
Lumbar (n = 324)	1		
Cervical (n = 330)	2.8	1.5–5.0	< 0.01

Covariates used in logistic regression analysis: mechanism of injury, highest fractured level, age group and sex (only in SCI analysis). ASOI includes non-spinal ASOIs and SCIs.

5.2 Survival after traumatic spinal fracture (Study II)

In total, 947 patients met the criteria for TSF and were included in Study II. Patient characteristics are represented in Table 10**.**

Table 10. Patient characteristics of traumatic spinal fracture patients in Study II.

Characteristic	TSF 2007–2011
Number of cases	947
Gender; n (male) / n (female)	565/382
Age; mean ± SD	53 ± 21.9
Invasive treatment; n (%)	
Spinal surgery	364 (38.4%)
Vertebro-/kyphoplasty	40 (4.2%)
Level of injury; n (%)	
Cervical	279 (29.5%)
Thoracic	176 (18.6%)
Lumbar	315 (33.3%)
Sacrum	62 (6.5%)
Cervical + thoracic	41 (4.3%)
Cervical + lumbar	5 (0.5%)
Thoracic + lumbar	64 (6.8%)
Cervical + thoracic + lumbar	5 (0.5%)
SCI; n (%)	94 (9.9%)
Brain injury; n (%)	69 (7.3%)
ASOI (non-spinal); n (%)	232 (24.5%)

ASOI includes intra-abdominal injury, lung injury, limb fracture and other remarkable injury or brain injury excluding SCI.

5.2.1 Survival

Of the 947 patients, 227 (24.0%) had died by the end of the follow-up period. The mean age at death was 75.9 years (± 15.2). The mean age was lower in males (71.1 ± 15.4 years, n = 132) than it was in females (82.6 ± 12.0 years, n = 95; $p < 0.01$).

The 1- and 5-year mortality rates were, overall, 6.8% and 19.1%, respectively, while these were, respectively, 7.4% and 19.3% for males, and 5.8% and 18.8% for females. The in-hospital mortality was low, as only 0.8% of the patients died during their hospital stay (Study I). As seen in Figure 9, it seems that the mortality in the age group of those over 65 years old is at its highest during the first few months following injury. Survival times according to gender and fracture level are represented in Figure 10 and Figure 11. SCI patients had high mortality rates: 12.8%

in the first 3 months, 17.0% in the first year and 37.2% in 5 years. Compared to the general population of Northern Finland, the excess mortality after TSF was 0.9% both in the age group up to 29 years old and in that of 30–49 years old; in addition, it was 4.0% among those aged 50–64 years old and 11.2% in the oldest age group of those over 65 years old.

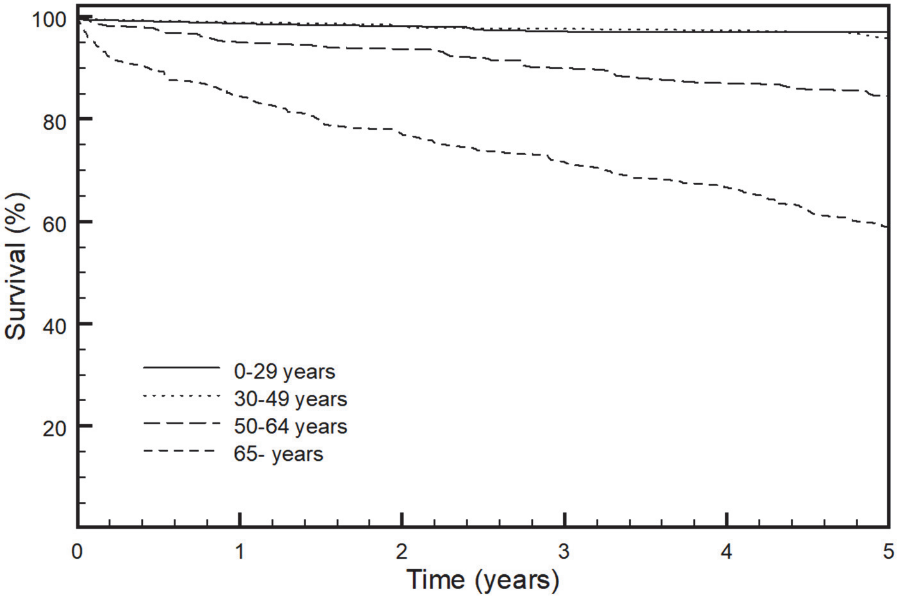

Fig. 9. Survival after traumatic spinal fracture according to age group.

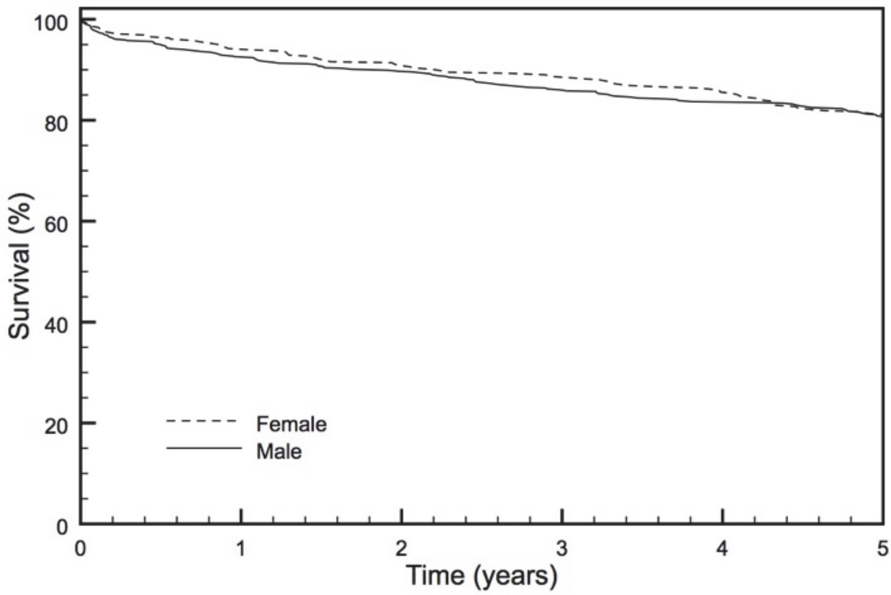

Fig. 10. Survival after traumatic spinal fracture according to gender.

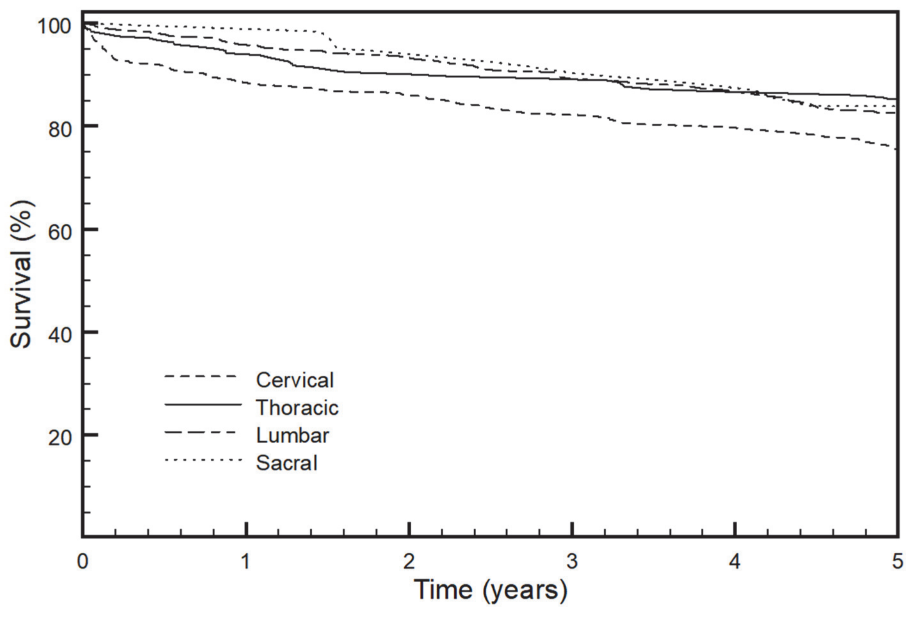

Fig. 11. Survival after traumatic spinal fracture according to the highest fractured level.

The age-adjusted 1-year SMR was 4.1 (95% CI: 3.2–5.3). The 1-year SMRs in different age groups were as follows: 19.8 (95% CI: 3.3–65.4) in the age group up to 29 years, 5.9 (95% CI: 0.98–19.4) in the group of 30–49 years, 7.2 (95% CI: 3.8–12.5) in the group of 50–64 years and 3.1 (95% CI: 2.3–4.0) in the group of over 65 years (age-adjusted). The SMRs of the oldest age groups, according to gender, are presented in Figure 12. The age-adjusted 1-year SMRs at different time points in the oldest age group were also calculated: from 0.5–1.5 years, the SMR was 2.3 (95% CI: 1.6–3.2), from 1–2 years is was 1.9 (95% CI: 1.3–2.9) and from 2–3 years it was 1.5 (95% CI: 0.9–2.4). This indicates that the mortality of TSF approaches the mortality of the general population two years after the injury. The HRs for death in the age groups of 50–64 and over 65 years are represented in Table 11. Low fall as a trauma mechanism had the most remarkable risk factor for death in both age groups.

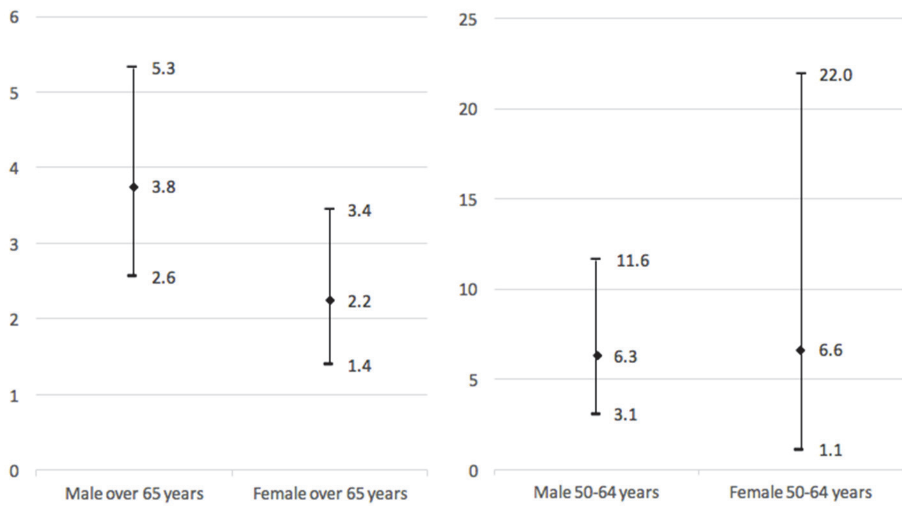

Fig. 12. The 1-year standardized mortality ratios and their 95% confidence intervals according to gender in the 2 oldest age groups.

Table 11. Hazard ratios for death (95% CI) in the 2 oldest age groups.

Age group	HR	95% CI	p-value
50–64 years (n = 206)			
Males	2.97	1.35–6.51	< 0.01
Mechanism of injury			
Road traffic accident	1 (ref.)		
Low fall	9.39	3.10–28.46	< 0.01
High fall	2.15	0.66–7.04	0.21
ASOI	2.70	1.31–5.56	< 0.01
Over 65 years (n = 306)			
Males	1.63	1.18–2.25	< 0.01
Mechanism of injury			
High fall	1 (ref.)		
Low fall	10.18	3.74–27.70	< 0.01
Road traffic accident	4.01	1.34–12.01	0.01
SCI	1.83	1.16–2.89	< 0.01

Patients with violence, sports, other or unknown as a trauma mechanism were excluded from the analysis in both groups (n = 28 in those aged 50–64 years; n = 12 in those aged over 65 years). The covariates used in the analysis were as follows: gender, mechanism of injury, fracture level, SCI, brain injury and ASOI (including intra-abdominal injury, lung injury, limb fracture and other remarkable injury excluding SCI and brain injury).

5.2.2 Causes of death

In a 4-year follow-up, the most common causes of death were circulatory diseases (54 patients, 36.7% of all deaths), accidents (32 patients, 21.8%) and neoplasms (20 patients, 13.6%). The causes of death after TSF compared to those in the general population are represented in Table 12. Accident or suicide was the cause of death for 32 patients (21.8%), and for these patients, an ICD-10 diagnosis code was recorded to describe the injury leading to death. The ICD-10 code was a spinal injury for 24 patients (16.3%), of which the injury was cervical in 19 cases and thoracolumbar in 5. Moreover, spinal injury was a contributory death cause for 14 patients, of which the injury was cervical in 10 patients and thoracolumbar in 4. This indicates that the spinal fracture was regarded as a significant factor in the chain of events leading to death for these 38 patients (i.e., 25.9% of the 147 patients who had died after 4 years). The immediate death causes of these 38 patients were pneumonia in 20 cases (52.6%), brain injury and myocardial infarction in 3 cases each (7.9% for each), respiratory distress syndrome and sepsis in 2 cases each (5.3%

for each) and interstitial lung disease in 1 case (2.6%). Data was missing for 7 patients.

Table 12. Causes of death at a four-year follow-up after traumatic spinal fracture compared to the general population of Northern Finland.

Cause of death	Number of patients (%)		p-value
	TSF patients	General population	
Disease of the circulatory system	54 (36.7%)	13,344 (41.0%)	0.30
Accident	32 (21.8%)	1,765 (5.4%)	< 0.01
Cancer or tumour	20 (13.6%)	7,352 (22.6%)	< 0.01
Dementia, Alzheimer's disease	11 (7.5%)	3,596 (11.0%)	0.17
Alcohol-related diseases	10 (6.8%)	1,218 (3.7%)	0.05
Suicide	5 (3.4%)	725 (2.2%)	0.34
Disease of the digestive system	4 (2.7%)	840 (2.6%)	0.91
Other disease of the nervous system	3 (2%)	769 (2.4%)	0.80
Diabetes	3 (2%)	377 (1.2%)	0.32
Disease of the respiratory system	2 (1.4%)	1,378 (4.2%)	0.08
Other	3 (2.0%)	1,197 (3.7%)	0.29
Total	147 (100%)	32,561 (100%)	

The general population includes all deaths from 2007–2011 in Northern Finland. Alcohol-related diseases include accidental poisoning by alcohol.

5.3 Epidemiology of acquired non-traumatic spinal cord injuries (Study III)

A total of 430 patients with acquired NTSCI were admitted to Tampere UH (2012–2015) and Oulu UH (2013–2016) in a 4-year period. Table 13 shows the overall characteristics of the study sample.

5.3.1 Incidence

The incidence of NTSCI was 54.1/1,000,000 per year. Table 13 shows the incidence rates in different age groups. Incidence increased with age, being highest in the age group of those aged 60–74 years (127.2/1,000,000 per year; Table 14). The yearly incidence grew during the study period, as seen in Table 15**.** The incidence of NTSCI requiring inpatient rehabilitation was 23.2/1,000,000 per year.

5.3.2 Age and gender

NTSCI was more common in males (n = 260, 60.5%) than it was in females (n = 170, 39.5%). The mean age was 62.0 (± 14.6) years, 60.5 (± 14.3) years for males and 64.2 (± 14.9) for females ($p < 0.01$). The age distribution is shown in Table 13.

5.3.3 Aetiology

The related aetiologies and their characteristics are shown in Table 16. Degenerative diseases were the most common aetiology of NTSCI, causing more than half of the injuries (n = 219, 50.9%). Most of the degenerative diseases consisted of spinal stenosis (n = 162, 73.9%), followed by a vertebral disc herniation (n = 57, 26.0%). The other aetiology group included injuries caused by inflammatory or autoimmune diseases in 12 cases (2.8% of all cases), syringomyelia in 6 cases (1.4%), osteoporosis or other metabolic disorders in 7 cases (1.6%) and spinal cord herniation in 1 case (0.2%). Degenerative diseases caused tetraplegia more often than they caused paraplegia, distinguishing them from other aetiologies ($p < 0.01$). As seen in Table 16, AIS D injuries were common, especially in injuries caused by benign tumours, with 36 patients (87.8% of patients), and degenerative diseases, with 168 patients (76.7%). No statistically significant difference was found in the mean age for different aetiologies ($p = 0.27$). The median LOS was substantially higher for infectious and vascular aetiologies, at 84 days and 43 days, respectively.

5.3.4 Level of injury and classification

A total of 177 patients had tetraplegia (41.1%) and 249 patients had paraplegia (57.9%), and data was missing in 4 cases (0.9%). Neurological examination found the single neurological level to be cervical (C0–C8) in 160 patients (37.2%), thoracic (T1–T12) in 179 (41.6%), lumbar (L1–L5) in 49 (11.4%) and sacral (S1–S5) in 3 (0.7%) patients. It remained unknown in 39 (9.1%) cases. The injury was complete (AIS A) in 22 cases (5.1%). The majority, 304 patients (70.7%), had an AIS D injury, 24 (5.6%) had an AIS B injury and 41 (9.3%) had an AIS C injury. AIS classification was missing for 40 patients (9.2%).

Table 13. Overall characteristics of non-traumatic spinal cord injury patients.

Characteristic	NTSCI 2012–2016[1]
Number of patients (population)	430
Incidence per year/1,000,000 (95% CI)	54.1 (49.1–59.6)
Gender; male (%) / female (%)	260 (60.5%) / 170 (39.5%)
Age; mean ± SD	62.0 ± 14.6
Median (range)	64.4 (12.2–99.2)
Level of injury; tetraplegia (%) / paraplegia (%)	177 (41.1%) / 249 (57.9%)
LOS; days, median (range)	14.5 (1–252)
Mean ± SD	36.1 ± 46.0
Spinal surgery; n (%)	367 (85.3%)
Inpatient rehabilitation; n (%)	189 (44.0%)
Severity of injury[2]; n (%)	
C1–C4 AIS A, B or C	11 (2.6%)
C5–C8 AIS A, B or C	8 (1.9%)
T1–S5 AIS A, B or C	66 (15.3%)
AIS D	304 (70.7%)
Unknown	41 (9.5%)
Age distribution; n (%)	
0–14 years	1 (0.2%)
15–29 years	10 (2.3%)
30–44 years	42 (9.8%)
45–59 years	115 (26.7%)
60–74 years	183 (42.6%)
75+ years	79 (18.4%)

[1]This included NTSCI treated in Tampere UH from 2012–2015 and Oulu UH from 2013–2016; [2]According to AIS score and injury level

Table 14. Incidence of non-traumatic spinal cord injury in different age groups.

Age (years)	Patients (n)	Incidence per million per year (95% CI)
0–14	1	0.8 (0.1–5.5)
15–29	9	6.7 (3.5–12.8)
30–44	37	27.7 (20.1–38.3)
45–59	110	73.0 (60.5–88.0)
60–74	178	127.2 (109.8–147.3)
Over 75	75	109.0 (86.9–136.7)

Table 15. Annual incidences of non-traumatic spinal cord injury patients between 2012 and 2016.

Year	Patients (n)	Population	Incidence per year per million (95% CI)
2012[1]	35	1,274,226	27.5 (19.7–38.3)
2013	79	1,850,415	42.7 (34.2–53.2)
2014	107	1,852,893	57.7 (47.8–69.8)
2015	123	1,853,437	66.4 (55.6–79.2)
2016[2]	66	741,807	89.0 (69.9–113.2)

[1]Only at Tampere UH; [2]Only at Oulu UH

5.3.5 Characteristics of treatment

The mean and median LOS were 32.4 days (± 41.0) and 14.5 days (range: 1–252 days), respectively. Inpatient rehabilitation was needed in 189 cases (44.0%). A total of 367 patients needed spinal surgery (85.3%), and 28 patients (7.4%) received intensive care. Most of the patients were discharged to their home or another private residence (n = 208, 48.4%), or to another hospital (n = 146, 34.0%). The rest were discharged to a nursing home (n = 10, 2.3%), assisted living residence (n = 6, 1.4%) or other facility (n = 4, 0.9%), and data was missing for 56 patients (13.0%). In addition, 25% were able to walk without assistance at discharge (n = 111). A majority of the patients needed a wheelchair (n = 121, 28.1%) or a wheeled walker (n = 121, 28.1%). A walking stick was needed in 47 cases (10.8%), while 29 patients were bed patients (6.7%) and 2 patients died during their hospital stay (0.5%). Data was missing for 2 patients (0.5%). None of the patients were ventilatory-dependent at discharge.

Table 16. Characteristics of non-traumatic spinal cord injuries in different aetiologies.

Characteristic	Degenerative	Malignant tumour	Benign tumour	Vascular	Infection	Other
n (% of all)	219 (50.9%)	88 (20.5%)	41 (9.5%)	35 (8.1%)	21 (4.9%)	26 (6.0%)
Incidence (per 1,000,000/year)	27.7	11.2	5.3	4.2	2.5	3.3
Gender (male/female); n (%)	151 (68.9%) / 68 (31.1%)	49 (55.7%) / 39 (44.3%)	18 (43.9%) / 23(56.1%)	19 (54.3%) / 16 (45.7%)	14 (66.7%) / 7 (33.3%)	9 (34.6%) / 11 (65.4%)
Age; years, mean (SD)	61.8 (14.6)	64.2 (13.0)	59.2 (15.6)	64.2 (15.8)	61.7 (13.2)	57.0 (17.5)
LOS; days, median (range), mean (SD)	8 (2–223) 26.6 (± 35.2)	15.5 (4–170) 27.7 (± 31.7)	12 (2–101) 23.3 (± 24.1)	43 (2–248) 55.9 (± 59.9)	84 (7–245) 75.2 (± 61.8)	29 (1–180) 45.5 (± 51.3)
Spinal surgery; n (%)	215 (98.2%)	66 (75.0%)	41 (100%)	13 (37.1%)	18 (85.7%)	14 (53.8%)
Need for ICU treatment; n (%)	5 (2.7%)	3 (3.9%)	2 (5.3%)	11 (33.3%)	5 (23.8%)	2 (7.7%)
Injury level; tetraplegia/paraplegia n (%)	133 (61.3%) / 84 (38.7%)	9 (10.3%) / 78 (89.7%)	10 (25.0%) / 30 (75.0%)	7 (20.0%) / 28 (80.0%)	8 (38.1%) / 13 (61.9%)	10 (38.5%) / 16 (61.5%)
Severity of injury*; n (%)						
C1–C4 AIS A, B or C	6 (2.7%)	0	0	2 (5.7%)	2 (9.5%)	1 (3.8%)
C5–C8 AIS A, B or C	4 (1.8%)	1 (1.1%)	0	2 (5.7%)	0	1 (3.8%)
T1–S5 AIS A, B or C	19 (8.7%)	22 (25.0%)	3 (7.3%)	12 (34.3%)	5 (23.8%)	5 (19.2%)
AIS D	168 (76.7%)	53 (60.2%)	36 (87.8%)	16 (45.7%)	14 (66.7%)	17 (65.4%)
Unknown	22 (10.0%)	12 (13.6%)	2 (4.9%)	3 (8.6%)	0	2 (7.7%)

Characteristic	Degenerative	Malignant tumour	Benign tumour	Vascular	Infection	Other
Mobility at discharge; n (%)						
Without assistance	71 (32.4%)	9 (10.2%)	16 (39.0%)	7 (20.0%)	1 (4.8%)	4 (15.4%)
Wheelchair	41 (18.7%)	34 (38.6%)	8 (19.5%)	19 (54.3%)	10 (47.6%)	9 (34.6%)
Wheeled walker	70 (32.0%)	21 (23.9%)	12 (29.3%)	3 (8.6%)	6 (28.6%)	9 (34.6%)
Walking stick	29 (13.2%)	9 (10.2%)	4 (9.8%)	2 (5.7%)	1 (4.8%)	2 (7.7%)
Bed patient	7 (3.2%)	13 (14.8%)	1 (2.4%)	3 (8.6%)	3 (14.3%)	2 (7.7%)
Unknown or dead	1 (0.5%)	2 (2.2%)	0	1 (2.9%)	0	0

NA= not applicable; *According to AIS and injury level

6 Discussion

The incidence of TSIs from 2007–2011 was found to be 26/100,000 per year in Northern Finland. The most common trauma mechanism was low fall. Nearly one-third of the TSI patients had ASOI, and in every tenth case, a concomitant SCI was present. The majority of the TSI patients in our study, 99.4%, sustained a spinal fracture; thus, a comparison between studies including only TSF patients and our study is acceptable.

The mortality after TSF was 7% after 1 year and 19% after 5 years of follow-up. Compared to the general population, mortality increased in all age groups, with 1-year SMRs ranging from 3.1 in the elderly (i.e., over 65 years) to 19.8 in the age group of those under 30 years old.

The incidence of NTSCI, in contrast, was found to be 54/1,000,000 per year in the main SCI care responsibility area of Oulu UH and Tampere UH between 2012 and 2016. Degenerative diseases were the most common aetiology. With an incidence of 71%, the proportion of motor-incomplete AIS D injuries was high.

6.1 Epidemiology of traumatic spinal injuries (Study I)

6.1.1 Incidence, age and gender distribution

The incidence of TSIs between 2007 and 2011 was found to be 26/100,000 per year in Northern Finland and 35/100,000 per year in the Oulu UH main responsibility area. The difference in the incidences is caused by the role of Oulu UH as a secondary care hospital for its own hospital district and as a tertiary referral hospital for Northern Finland. We did not have access to the patient care registers of central hospitals in Northern Finland; thus, patients treated only in central hospitals were not included in the study. Our incidence is comparable to the previous results of 27/100,000 per year from Central Finland (Somersalo et al., 2014). The catchment area of the previous Finnish study was similar to the Oulu UH main responsibility area, which would indicate slightly higher incidence in our study. However, it must be considered that they included only patients treated on trauma wards, whereas the present study included all patients evaluated and treated in Oulu UH, including in the emergency department. A recent nationwide Finnish study based on National Hospital Discharge Register data reported a higher annual incidence than that in the present study, at 57–89/100,000, in relation to hospitalised spinal fractures from

1998–2017 (Ponkilainen et al., 2019). In addition, the incidence of surgically treated spine fractures of 5.3–8.8/100,000 per year in their study was slightly lower than our result of 10.3/100,000. Geographical differences may partly explain the differences in incidence rates, as our study only represents the incidence rate in Northern Finland. However, the most probable explanation is the difference in study design. In our study, conservatively treated patients may be underestimated, as the study took place in a tertiary care hospital where spinal surgery is centralised. As a register-based study, their study sample also included patients treated conservatively in primary health care. In addition, as all patient records were manually reviewed in our study, we could exclude fractures without evident trauma (e.g., prevalent osteoporotic fractures with the wrong ICD-10 code), which could also partly explain the lower incidence. The review of the patient records probably also explains the slightly better coverage of surgically treated patients in our study.

There are not many previous studies internationally related to the epidemiology of TSI covering the whole spine. A recent study reported an annual incidence of 31/100,000 for TSFs in Iceland—a similar result to that of our study (Kristinsdottir et al., 2018). As a Nordic country, Iceland shares a similar cultural and economic setting to Finland. In Ireland, the annual incidence of hospitalised TSF patients has been shown to be 20/100,000 (Roche et al., 2008). In contrast, a significantly higher incidence of 64/100,000 per year has been reported in Canada (Hu et al., 1996). In Asia, the reported incidence has varied from 17–62/100,000 (Grivna et al., 2015; Liu et al., 2018; Yang et al., 2008). Our result seems to be in the mid-range compared to these previous international results.

The incidence of spinal surgery due to TSI was 10/100,000 per year, similar to previous findings from Belgium (Du Bois & Donceel, 2010). The surgical rate in our study population was 39%, which was in the same range as that reported in an Irish study (with a rate of 35%) and in a Chinese study (with a rate of 44%; Lenehan et al., 2009; Liu et al., 2012).

The mean age of 53 years in our study was higher than the mean ages of 32 years, 44 years and 46 years reported in Irish, German and Chinese studies, respectively (Lenehan et al., 2009; Leucht et al., 2009; Wang et al., 2012). The higher mean age reflects the trauma mechanism distribution, with low fall being the leading aetiology in our study. A similar result to ours was reported in Iceland, where the mean age of TSI patients was found to be 56 years (Kristinsdottir et al., 2018). The sex distribution of TSI patients was male-dominated in our study population, and that was in line with the results from previous studies (Hu et al., 1996; Kristinsdottir et al., 2018; Lenehan et al., 2009; Leucht et al., 2009; Liu et al., 2012; Pirouzmand, 2010; Wang et al., 2012). Considering age groups and trauma mechanisms, the male-dominant sex distribution seems to arise from those aged 15–60 years old and from high-energy injuries, for which males are clearly overrepresented.

6.1.2 Aetiology

With an incidence of 36%, low fall was the most common trauma mechanism in the present study, a different result than that of most previous studies on the subject. In Germany and China, high falls have been reported to be the leading cause of TSF, with low falls accounting for only 20% and 22% of the injuries, respectively (Leucht et al., 2009; Wang et al., 2012). In contrast, in Irish populations, road traffic accidents have been documented to be the most common aetiology, causing 34–42% of cases (Lenehan et al., 2009; Roche et al., 2008). A similar result to ours was found in Iceland, where low fall was the leading cause of TSF, with a proportion of 33% (Kristinsdottir et al., 2018). The aetiology distribution in the present study supports the data from previous studies showing an increasing proportion of low falls as mechanism of TSI (Fredo et al., 2012; Kattail et al., 2009). The differences in healthcare systems between countries may have effect on the aetiology distribution in the studies; for example, high-energy injuries may be over-represented in some studies from trauma centres.

The aetiology distribution varied between different age groups: road traffic accidents were the most common trauma mechanism in younger patients (i.e., under 45 years old) and low falls in elderly patients (i.e., over 60 years old). The role of osteoporosis was not studied, but the mean age of 69.3 years in the low-fall group and the fact that low fall accounted for 49% of the injuries in females indicate that osteoporosis may have had a role in the cases in the study population. It must be highlighted, however, that we strictly included only cases with clear traumatic aetiology.

TSI can result in serious consequences for individuals and burdens the field of health care. In the elderly, the preventive measure that should be particularly targeted is the prevention of low falls. The economic burden of all fall-related injuries in the elderly is enormous—for example, in the US in 2015, it cost US$50 billion (€45 billion)—emphasising the importance of prevention (Florence et al., 2018). Known risk factors for falling include fear of falling, balance or gait problems, medication (e.g., polypharmacy), cardiovascular conditions, cognitive impairment, lower limb pain and urinary incontinence (e.g., as this may cause one to rush to the bathroom at night; Vieira, Palmer, & Chaves, 2016). Together with clinical experience, screening for risk factors can help clinicians to identify patients for whom the primary prevention should be especially targeted.

In addition, secondary prevention is important, as patients who have fallen during the past 12 months are known to be at increased risk to fall again (Vieira et al., 2016). Clinicians should ask about previous falls, as patients often do not report previous falls spontaneously, especially if they did not cause any injury. In secondary prevention, an investigation of the reason for previous falls and the further targeting of possible preventive measures to address the reasons for them is crucial to preventing future falls (e.g., circumstances such as the place of the fall and preceding symptoms should be asked about). However, finding out the underlying cause can often be challenging. In addition, an assessment of drug use should be done, as polypharmacy has been shown to increase the risk of falling (e.g., because of the use of sedatives, antipsychotics, neuroleptics or antihypertensives; Vieira et al., 2016).

Different exercise programmes have been reported to be effective interventions for preventing falls. The difficulty level of the programmes should be individually assessed to ensure the safety of the exercises. According to Cochrane's review on the subject, programmes containing multiple categories—usually balance and muscle strength exercises—have the best evidence of success, and they can be delivered as group or individual home exercises (Gillespie et al., 2012). A meta-analysis on the subject suggested that exercises that seek to improve balance are ideal and that exercise should be done at least three hours per week (Sherrington et al., 2017). Exercise programmes have been shown to be effective in patients with and without risk factors for falling (Gillespie et al., 2012; Sherrington et al., 2017). In addition, especially among patients with increased risk, home safety interventions seem to be effective (Gillespie et al., 2012).

Due to the fragmentation of health care, primary health care has the best opportunity to influence fall prevention. However, due to the limited resources available, this can be challenging. Interventions also have positive health effects other than preventing fall-related injuries, as they may reduce functional decline and frailty and increase socialisation and self-esteem (Vieira et al., 2016). Thus, taking into account the health effects for the individual and the economic burden for society, it could be worth identifying patients who would benefit from such interventions and organising exercise classes for subgroups, for example, despite the limited resources available. In the future, the growing role of technology, however, could offer solutions to the issue of limited resources. There are promising results related to wearable acceleratory sensors, which detect features in gait that could—together with the automatic screening of known risk factors from patient data—offer new low-cost possibilities for recognising patients in need for intervention to reduce falls (Immonen, 2020).

6.1.3 Associated injuries

Nearly one-third of the patients with TSI had ASOIs in our study, which was on the same scale as the figures from a previous Chinese study (Wang et al., 2012). However, despite the high frequency of ASOIs, this was lower than the results of most similar studies (den Ouden et al., 2019; Hu et al., 1996; Leucht et al., 2009; Saboe et al., 1991). These previous studies did not account SCI for an ASOI. Similar to what has been reported in previous studies, high-energy injuries increased the risk for ASOI in the present study: the odds of having an ASOI for patients in the road traffic accident and high-fall groups were 2.7 and 2.4 times higher, respectively, compared to the low-fall group (Hu et al., 1996; Wang et al., 2012). As previously stated, low falls composed the biggest aetiology group in our study population. Thus, the aetiology distribution may be one of the possible explanations for the lower frequency of ASOI in our study. Furthermore, the lower frequency may be explained by the probable tighter criteria for injuries that were counted as ASOIs in our study. Most of the previous studies did not specify the criteria for ASOI in different anatomic locations. The criteria in the present study included only injuries that had an effect on the course of treatment or prognosis. Brain injury, instead of head injury, was counted as its own category, and abdominal and thorax injuries were only counted if they required draining or surgical intervention.

SCI was found in 10% of the TSI patients in our study. The previously reported frequency of SCI among TSF patients has varied between 9% and 44%; thus, our result stands on the lower end of the range (Fletcher et al., 1995; Hu et al., 1996; Kristinsdottir et al., 2018; Leucht et al., 2009; Oliver et al., 2012; Wang et al., 2012). An interesting finding was that low falls were the leading cause of SCI, whereas all other ASOIs were most likely due to high-energy injuries. SCIs due to low falls often took the form of cervical traumas in older people. A recent Finnish study reported a similar finding of low falls being the leading trauma mechanism for SCIs (Koskinen et al., 2014). Before the year 2000, a trend of a continuously increasing number of cervical TSCIs caused by low falls among the elderly had been observed in a Finnish nationwide register-based study (Kannus, Niemi, Palvanen, & Parkkari, 2000). After 2000, however, the incidence rates of mostly fall-induced hip fractures and fall-induced deaths among older adults changed course from an increasing to a declining trend in Finland (Kannus, Niemi, Parkkari, & Sievanen, 2018; Kannus, Niemi, Sievanen, & Parkkari, 2018). In our study, low falls caused nearly 70% of SCIs in elderly patients over 60 years old, an important finding when considering preventive measures. In contrast, more than half of SCIs in those under 45 years old were caused by road traffic accidents. From both a humane and an economical point of view, SCIs in younger age groups cause a major burden, as a longer life expectancy means more years with a lower quality of life and higher economical costs; for this reason, preventive measures should be focused on road traffic accidents for the young.

TBI was found in 7% of the patients. Comparing this result to those of previous studies is difficult, as past studies have combined TBIs with other head injuries. Oliver et al. (2012) found that severe head injuries (Abbreviated Injury Scale ≥ 3) were present in 33% of TSI patients. They also reported that the Glasgow Coma Scale score at admission was ≤ 8 in 14% of the cases. Although the reported variables in their study differ from our TBI variable, their results seem considerably higher than ours. They reviewed patient records in a trauma registry (Los Angeles, US; Southern California, US), which together with cultural differences may partly explain the higher proportion of brain injuries. The incidence rate of associated head injuries among TSI patients in other studies has ranged between 14% and 26% depending on the study (Hu et al., 1996; Leucht et al., 2009; Saboe et al., 1991; Wang et al., 2012). The most common trauma mechanisms leading to TSI with associated TBI were road traffic injuries followed by high falls, providing similar results to the previous data about head injuries (Leucht et al., 2009; Wang et al., 2012). In our study, TBI was also overrepresented in cervical injuries (11% of all cervical injuries). On the grounds of these results, TBI should be suspected especially in patients with high-energy injury mechanisms and cervical injury. When considering preventive measures, one subgroup was clearly overrepresented and should be targeted: road traffic accidents in young adults aged 15–29 years old (20 TBIs of the 71 TBIs in total, 28%).

Furthermore, as rehabilitation after an SCI requires major learning abilities, cognitive impairment after a TBI may make the rehabilitation process even more challenging. Moderate to severe dual diagnosis patients are less efficient in obtaining motor skills during inpatient rehabilitation, have continued cognitive impairment and are less likely to be discharged to their home when compared to SCI patients without TBI (Garlanger, Beck, & Cheville, 2018). Due to special challenges in rehabilitation, the recognition of these patients is important. The incidence of co-occurring TSCI and TBI in patients was 14% among all TSCI patients (a total of 14 patients, 1.4% of the whole study sample).

6.2 Survival after traumatic spinal fracture (Study II)

6.2.1 Survival

The mortality in our study was 6.8% after the first year and 19.1% after 5 years. Compared to the general population, mortality was higher in all age groups, with the SMR being 3.1 in the oldest age group and 19.8 in those under 30 years.

There is not much data about survival rates after TSF in the literature. Most of the previous studies dealt with osteoporotic spinal fractures (Bliuc et al., 2009; Center et al., 1999; Hasserius et al., 2003). The 5-year SMRs after osteoporotic spinal fracture resulting from low-energy injuries were 1.7–1.8 in females and 2.4 in males in 2 Australian prospective studies with the same cohort (Bliuc et al., 2009; Center et al., 1999). A study from South Korea reported 1-year mortality ratios and SMRs of 14.6% and 3.5, respectively, in males and of 7.2% and 2.5, respectively, in females after thoracolumbar spinal fractures in patients over 50 years old (Lee et al., 2012). The study made no distinction between low- and high-energy injuries. To compare our results to the ones above, we calculated the mortality ratio and SMR for thoracolumbar fractures in patients over 50 years old (i.e., the 2 oldest age groups combined). The 1-year mortality ratio was 8.5% for males, which was lower than that reported in South Korea, and 9.0% for females, which was higher than that reported in South Korea. The SMRs for isolated thoracolumbar fractures in those over 50 in our study were comparable with those of South Korea: 3.3 and 2.9 in males and females, respectively.

The increase in mortality after hip fracture is well known. When comparing the results of the present study to the figures of the most relevant studies about survival after hip fracture, it seems that the risk for death after TSF is quite similar to that after hip fracture. A meta-analysis of prospective cohort studies about survival after hip fracture reported a 1-year pooled risk for death of 2.9 for females and 3.7 for males (Haentjens et al., 2010). A study combining 8 cohorts from Europe and the US revealed a 1-year SMR of 2.8 in those aged over 60 (Katsoulis et al., 2017). The results are at the same level as the 1-year SMRs of 2.2 for females and 3.8 for males found in those aged over 65 years old in our study population. Vertebral and hip fractures have been shown to decrease posttraumatic survival more than other fractures do (Bliuc et al., 2009; Cauley, Thompson, Ensrud, Scott, & Black, 2000; Ioannidis et al., 2009). Both TSFs and hip fractures decrease the functional capacity and mobility of the patient. It may be possible that the increased mortality after both types of injury result from the same factors, such as age, morbidity and frailty leading to prolonged confinement to bed and a subsequent decrease in the health condition of the patient. Even a short immobilisation of an elderly person can lead to a considerable decrease in functional capacity and, further, to serious complications such as pneumonia.

6.2.2 Risk factors for death

Low fall as a trauma mechanism was found to increase the likelihood of death in the two oldest age groups. The significance of this finding is emphasised by the fact that low fall was also the most common aetiology for TSF in the elderly (see Study I). Low fall has also previously been shown to be an indicator for death in elderly trauma patients (Davidson et al., 2011; Wong et al., 2015). Fall-induced deaths had been increasing in Finland in the decades leading up to the year 2000, but after this time, the number has remained relatively stable, while the incidence rate has been declining (Kannus et al., 2018b). One reason that may explain the increased hazard for death is that the health of people who sustain a fracture due to low-energy mechanisms is already worse than that of their counterparts. This has been suggested before, although there have also been studies that found no evidence of the effect of underlying health on increased mortality (Browner, Pressman, Nevitt, & Cummings, 1996; Cauley et al., 2000; Tosteson, Gottlieb, Radley, Fisher, & Melton, 2007). According to our results, physicians should acknowledge the vulnerability of elderly patients who sustained a TSF as a result of a low fall, who need special attention in care. The acknowledgment of the increased risk of death in these patients is the first step in planning for their care, including not only the active rehabilitation of the injury and secondary prevention of new falls but also possible interventions for the general health of the patient. However, further studies focusing on this subgroup are needed to establish the underlying causes of the excess mortality, based on which treatment and rehabilitation can be further planned.

We found that the risk of death was increased in males compared to females in the two oldest age groups. The higher mortality of males has also been reported in relation to osteoporotic spinal fractures and in relation to TSF (Bliuc et al., 2009;

Lee et al., 2012; McKinley, Seel, & Hardman, 1999). The reason behind this remains unclear and is probably multifactorial. One study found that the excess mortality after trauma begins at 55 for men and 70 for women, which could be one of the underlying explanations for the gender difference (Wong et al., 2015).

A review of causes of death revealed that TSI was regarded as a significant factor in the chain of events leading to death for one-fourth of the patients who died in the first four years after TSI. Most of them were cervical injuries. In addition, cervical injuries had a higher mortality than did thoracolumbar injuries. The findings indicate that, compared to other spinal injuries, cervical injuries are often more severe, and the injury itself leads to death more often. It has been reported that fatal cervical injuries have been increasing in Finland in the past few decades (Thesleff, Niskakangas, Luoto, Ohman, & Ronkainen, 2016). It has also been suggested that 28% of the deaths that occur after TSF are related to the fracture itself, similar to our findings concerning death causes (Kanis, Oden, Johnell, De Laet, & Jonsson, 2004). These findings indicate that cervical fractures alone do not explain the excess mortality, and further studies are needed on the subject. Previously, frailty was suggested as one of the explaining factors behind the increased mortality after low-fall-induced injuries. In addition, decreased mobility and other consequences of the fracture are possible explanations for the mortality. It is also possible that risk behaviour such as substance abuse is overrepresented in populations that have sustained a traumatic fracture, and that could explain part of the excess mortality. This is supported by the fact that there was a statistically significant difference between alcohol-related deaths in the TSF population (6.8% of all deaths) and in the general population (3.7%) in our study.

6.3 Epidemiology of non-traumatic spinal cord injuries (Study III)

6.3.1 Incidence, age and sex distribution

The annual incidence of acquired NTSCI was 54.1/1,000,000 in our study, which was substantially higher than that reported in most previous studies. In a recent Norwegian registry-based cross-sectional study, the incidence of NTSCI was found to be 7.7–10.4/1,000,000 per year (Halvorsen et al., 2019b). A global review of the epidemiology of NTSCI revealed a median annual incidence of 6/1,000,000 in Western Europe, almost 10 times lower than that found in our study (New et al., 2014). The 8 included Western European studies were old, with the most recent being published 15 years ago (Ronen et al., 2004). In Spain, a cohort study revealed an annual incidence of 11.4/1,000,000 (van den Berg et al., 2012). In the Czech Republic, a prospective study reported an incidence of 8.6/1,000,000 per year, but degenerative aetiologies were excluded (Kriz et al., 2017). Several epidemiological studies about NTSCIs have been conducted in Australia, and the incidence has been reported to be 26/1,000,000 per year, which is still lower than ours (New & Sundararajan, 2008). The only similar result to ours was reported from Canada: an incidence of 68/1,000,000 per year was estimated using population modelling and extrapolation (Noonan et al., 2012). Another Canadian study filtering diagnosis codes from a national healthcare register reported an incidence of 33/1,000,000 per year (Guilcher et al., 2017).

One explanation for the difference may be that some of the previous studies are registry-based, and they probably have a selection bias towards NTSCI, which leads to an underestimation of the incidence rate (New et al., 2014). It is noteworthy that the Canadian study, which reported as high an incidence rate as did the current study, calculated the incidence using the previously reported registry-based incidence of TSCI and the ratio of NTSCI to SCI (Noonan et al., 2012). Furthermore, one of the underlying reasons for the high incidence in our study is the fact that, due to the centralisation of SCI care in Finland, our study also included NTSCI patients not needing inpatient rehabilitation. In addition to mild injuries not needing inpatient rehabilitation, the number of elderly patients and NTSCI patients with malignant aetiologies may also have been underestimated in previous studies due to rehabilitation limits caused by reduced life expectancy, worsened health condition, lesser physical capacity or previously poor functional capacity, which may have been barriers to inpatient rehabilitation. The incidence of NTSCI needing inpatient rehabilitation was 23.2/1,000,000 per year, which is closer to but still higher than that reported in most previous studies.

The incidence of NTSCI also grew during the study period. Previously, the incidence of NTSCI was anticipated to grow due to the aging of the population worldwide (New & Sundararajan, 2008). However, the aging of the population alone does not explain the rapid growth of the incidence in our study. We suggest that one of the reasons for this may be a possible learning curve in treatment practices after the centralisation in 2011. SCIs may have become better recognised and the SCI rehabilitation teams may have become further informed during the study period.

If the incidence is generalised to the whole of Finland's population, approximately 300 cases of NTSCI occur in Finland yearly. Combined with TSCI (on the basis of the incidence of 38/1,000,000 reported by Koskinen et al., 2014), the total number of new SCI cases in Finland is around 510 cases annually. In 2017, a new healthcare act prescribed that the acute care, rehabilitation and lifelong follow-up of SCI patients should be centralised in fewer than five UHs (instead of the three UHs prescribed in 2011; Ministry of Social Affairs and Health, 2010, 2017). In 2020, there are approximately 43 inpatient rehabilitation places reserved for SCI patients in four UHs in Finland (Helsinki UH: 18 places; Tampere UH: 12 places; Oulu UH: 5 places; Turku UH: 8 places). The mean LOS of TSCI patients in Finland has been reported to be 70.5 days (Koskinen et al., 2014), and the present study showed a mean LOS of 36.1 days for NTSCI patients. On the grounds of these figures, 1 inpatient place per 10 NTSCI patients and 1 inpatient place per 5 TSCI patients is required annually, on average. As there are 300 NTSCI cases and 210 TSCI cases annually in Finland, further estimation reveals that a total of 72 inpatient rehabilitation places are needed: 30 for NTSCI and 42 for TSCI patients. Notably, some SCI patients also return for inpatient rehabilitation after the acute care period, which increases the number of places needed. Assessing the sufficiency of the resources on the basis of incidence numbers alone is challenging. These figures, however, indicate that the available 43 inpatient rehabilitation places may not be enough.

The mean age of 62 years in our study's NTSCI population is in line with that reported in most previous studies (Fortin et al., 2015; Guilcher et al., 2010, 2017; McKinley et al., 1999; New et al., 2015b; New et al., 2011a; van den Berg et al., 2012). The reported mean age of 55 years in the Norwegian study was lower than ours, however (Halvorsen et al., 2019b). Moreover, similar to our study, most previous studies have reported an even or slightly male-dominated sex distribution (Guilcher et al., 2010, 2017; Halvorsen et al., 2019b; McKinley et al., 1999; New et al., 2015b; New et al., 2011a; Ronen et al., 2004; van den Berg et al., 2012).

6.3.2 Severity of injury

The proportion of mild injuries in the present study was high, as 71% of the NTSCI cases were classified as AIS D. For comparison, an international multicentre study revealed a proportion 52% and a Norwegian study showed a proportion of 59% of NTSCIs being classified as AIS D (Halvorsen et al., 2019; New et al., 2015a). Many of the previous studies were based on data from rehabilitation centres, and mild injuries do not need inpatient rehabilitation as often as do more severe injuries (Guilcher et al., 2017; Gupta, Taly, Srivastava, & Murali, 2009; Kriz et al., 2017;

van den Berg et al., 2012). As previously stated, due to the centralisation of SCI care in Finland, the higher incidence in the present study can be partly explained by the fact that it also included less severe injuries not needing inpatient rehabilitation.

6.3.3 Aetiology

Degenerative diseases have been reported to be most common cause of NTSCI in developed countries (New et al., 2014). In our study, however, the proportion of 51% of NTSCIs being attributed to degenerative diseases was higher than that in most studies. An equally high proportion has been reported in the US (McKinley et al., 1999). A recent retrospective international multicentre study reported an incidence of 31% for degenerative aetiologies, which was the most common cause (New et al., 2015b). In the present study, cervical spinal stenosis was overrepresented in the degenerative diseases group. When considering preventive measures, the early recognition of the condition could be one of the main targets.

In an international multicentre study, aetiology proportions of 19% for vascular disorders and of 13% for infections were substantially higher than the proportions of 8% and 5%, respectively, found in the present study (New et al., 2015b). Instead, the proportions of malignant and benign neoplasms, 16% and 9%, respectively, were similar to our 20% and 10%.

6.3.4 Characteristics of treatment

Previously, the reported LOS has varied between 20 and 97 days, which is markedly higher than our median LOS of 14.5 days (Fortin et al., 2015; Gupta et al., 2009; Halvorsen et al., 2019b; New, 2005; New et al., 2015b; Vervoordeldonk, Post, New, Clin Epi, & Van Asbeck, 2013). The difference is probably explained by our study also including patients who did not need inpatient rehabilitation. In infective and vascular aetiologies, the median LOS was substantially longer than that in other aetiologies, being 84 and 43 days, respectively. Interestingly, the LOS in these aetiologies is comparable to the previously published median LOS of TSCI patients in Finland (Koskinen et al., 2014). Infectious diseases and vascular disorders have similar characteristics to traumatic injuries, as they often have a rapid onset and more often require inpatient rehabilitation compared to other more slowly progressing aetiologies. Moreover, infectious diseases often need long treatment courses with intravenous antibiotics, a factor that extends the LOS.

6.3.5 Comparison to traumatic spinal fractures

In Finland, the annual incidence of TSCI has recently been reported to be 38/1,000,000 in a setting similar to that of the present study from Oulu UH and Tampere UH, and the incidence was comparable to previous international results (Koskinen et al., 2014). Previously, NTSCIs have been reported to be more common than TSCIs (Ge et al., 2018; New & Sundararajan, 2008; Noonan et al., 2012). When comparing the incidence of NTSCI in the present study to the incidence of TSCI reported by Koskinen et al. (2014), the situation seems to be similar in Finland, too.

Severe injuries among the TSCIs included in the study by Koskinen et al. (2014) were more common than they were among NTSCIs in the present study: specifically, the proportion of severe cervical injuries (i.e., AIS A, B or C; 22%) among TSCI patients was remarkably higher than that among NTSCI patients (4%). Moreover, the proportion of 51% of AIS D injuries in TSCIs was markedly lower than the proportion of 71% in our study. Regarding TSCIs, 70% of TSCI patients were diagnosed with tetraplegia, which was higher than the proportion of 41% of patients with NTSCIs in the present study.

6.4 Strengths and limitations

Concerning Study I and Study II, the retrospective study design has its typical limitations, including reliance on the quality of the hospital care register used. However, the Finnish hospital discharge register has been proven to be reliable (Sund, 2012). Also, Statistics Finland's Archive of Death Certificates covers practically 100% of the people who die in Finland or who die abroad and are domiciled in Finland at the time of death. The major strength of Study I and Study II was that all patient records were reviewed by the researchers, in addition to the use of the statistical discharge registry. In Study III, the study sample was collected prospectively during the acute treatment period, a factor that increases the reliability of the results. In addition, all patients were evaluated according to the ISCoS Core Data Set by specialist rehabilitation doctors working in SCI rehabilitation units.

The study population in the present study was limited to patients who received inpatient or outpatient care in hospital. Thus, patients treated in primary health care or in the private sector were not included. Health care in Finland, however, is mainly public, and the acute phases of severe injuries are always treated in public hospitals. In addition, trauma-related spinal surgery in the hospital district of Oulu UH is centralised to Oulu UH. This can, however, lead to the overrepresentation of severe injuries, as Oulu UH acts as a tertiary level hospital to four central hospitals in Northern Finland, especially for spinal surgery and neurosurgery. Regarding Study III, the centralisation of SCI treatment in Finland in 2011 offered a great opportunity for epidemiological research. As the acute treatment, rehabilitation and lifelong follow-up became centralised in three UHs, we could include not only NTSCI patients needing inpatient rehabilitation but also patients with milder injuries and with barriers to inpatient rehabilitation in the present study. Including the third SCI centre (Helsinki UH) would have been optimal, but as the study was conducted in two out of the three SCI centres, covering over half of the SCI care in Finland, we think that the results of Study III can be generalised to the whole of Finland, for the most part.

In Study II, we did not have data on the health condition of the patients before the trauma, which could have had a causal relation to mortality. In Study III, we did not have data on survival or complications, which would have added value to the comparison of different aetiologies of NTSCI and the assessment of the outcome of rehabilitation. Also, the incidence of NTSCI in children may be underestimated, as some of the rare paediatric diseases are centralised outside the study hospitals. However, the possible number of these patients is very low, as only acquired NTSCIs were included in Study III.

The results in the present study should be cautiously generalised internationally, as the population structure, cultural circumstances, infrastructure and spectrum of diseases vary depending on the country. In addition, when comparing the results of this study to those of previous studies, it should be remembered that the different study settings should be considered.

In the future, considering the results of the present study, it would be useful to conduct epidemiological studies among certain subgroups, such as those who sustain a TSI as a result of a low fall. More detailed epidemiological data is needed to further develop efficient and targeted prevention strategies. From the perspective of public health and the economy, the prevention of injuries will need to be emphasised in the future, as there is a trend of population aging. Concerning SCIs, the centralisation of SCI care offers a unique opportunity for clinical and epidemiological research, as the whole patient group can now be taken into account, as seen in the results of Study III. It also makes nationwide multicentre studies possible. This offers potential benefits and opportunities that should be leveraged.

7 Conclusions

The present study provides a comprehensive view of the epidemiology of TSI and NTSCI, comparing it to previous international results. An overview of long-term survival after TSF is also presented. The incidence and treatment figures can be used to better plan the future use of resources. Knowledge of the aetiology and risk factors of the diseases and of associated adverse events are also essential for planning preventive measures, not only on a large scale but also in individual clinicians' daily work. The main conclusions of the study are as follows:

1. Regarding TSI, low falls should be the focus of prevention in the elderly, whereas in those under 45 years old, the preventive measures should be targeted towards road traffic accidents, especially as they are often related to serious ASOIs.
2. TSF increases mortality in all age groups compared to the general population, with the highest mortality rates occurring in the elderly and in males. The increase in mortality seems to be comparable to the increase in mortality after hip fracture. Patients who sustain a spinal fracture due to falling need special attention in care, as having low fall as the trauma mechanism increased the risk of death significantly.
3. The incidence of NTSCI was found to be markedly higher than expected on the basis of previous international studies. In future epidemiological studies, study settings should be carefully considered to take into account the entire patient group.

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List of original publications

I Niemi-Nikkola, V., Saijets, N., Ylipoussu, H., Kinnunen, P., Pesälä, J., Mäkelä, P., Alen, M., Kallinen, M., & Vainionpää, A. (2018). Traumatic Spinal Injuries in Northern Finland. *Spine*, *43*(1), E45–E51. https://doi.org/10.1097/BRS.0000000000002214

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III Niemi-Nikkola, V., Koskinen E., Väärälä E., Kauppila, A., Kallinen M., & Vainionpää, A. (2020). Incidence of Acquired Nontraumatic Spinal Cord Injury in Finland: A 4-Year Prospective Multicenter Study. (2020). *Archives of Physical Medicine and Rehabilitation.* Advance online publication. https://doi.org/10.1016/j.apmr.2020.08.015

Original publications are not included in the electronic version of the dissertation.

1581. Stenman, Päivi (2020) Iäkkäiden hoitotyössä toimivan henkilöstön kokemuksia työtyytyväisyydestä ja toimintaympäristöstä kinestetiikan käyttöönoton aikana

1582. Koota, Elina (2020) The development of an evidence-based practice educational intervention and its effectiveness on emergency nurses' attitudes, knowledge, skills, self-efficacy and behavior

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