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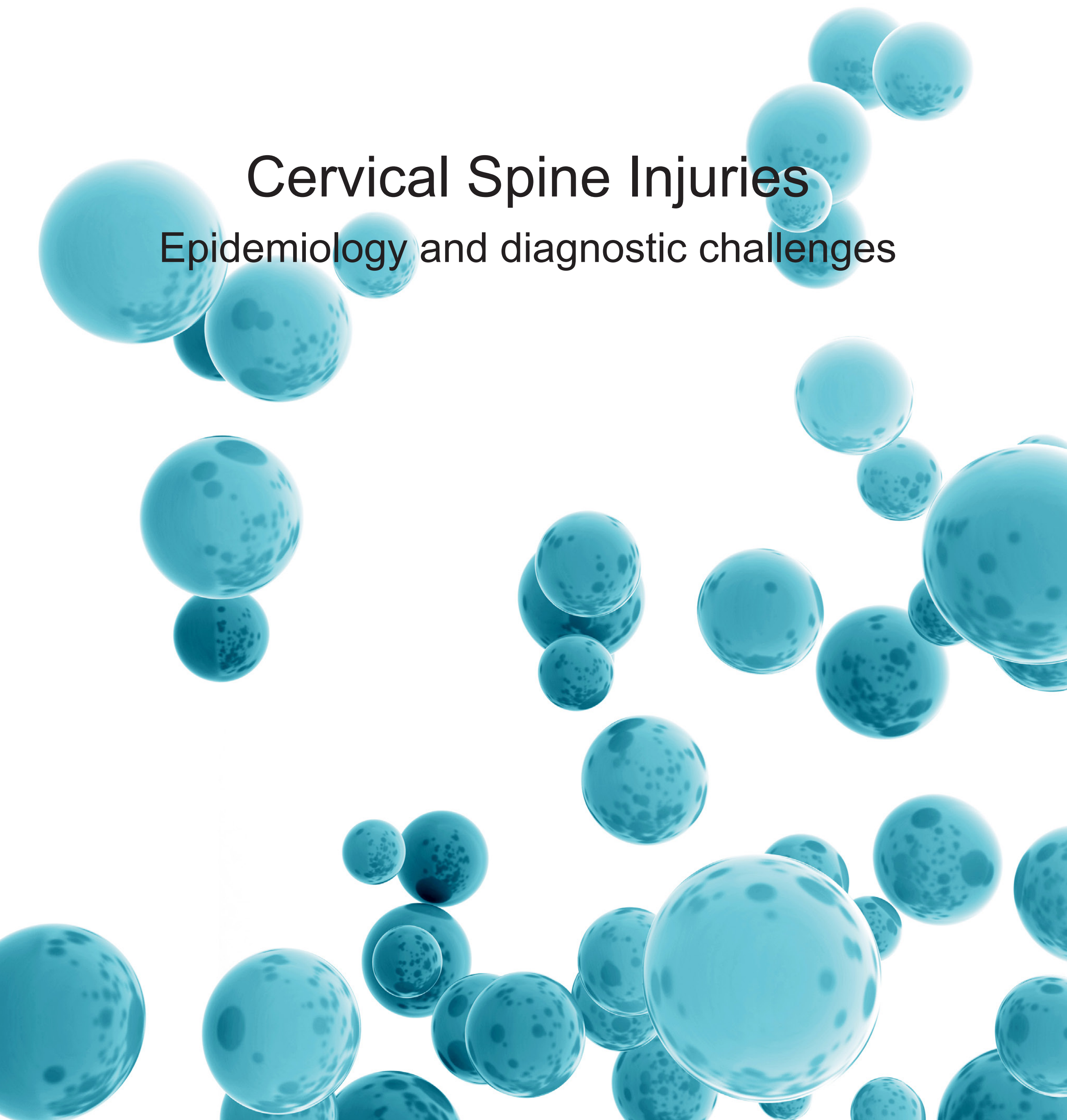
TUOMO THESLEFF

Cervical Spine Injuries

Epidemiology and diagnostic challenges



TUOMO THESLEFF

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Epidemiology and diagnostic challenges

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UNIVERSITY OF TAMPERE

TUOMO THESLEFF

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Epidemiology and diagnostic challenges

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ABSTRACT

Cervical spine injury (CSI) is a serious condition which may cause permanent disability or even death. CSI occurs in 2-7% of blunt trauma admissions. In countries with similar population demographics to Finland, the annual incidence of CSI is approximately 9-17/100,000 inhabitants. The number of patients with CSI, who succumb prior to hospitalization, is not well known. The most common injury mechanisms leading to CSIs are traffic accidents and falls, and the most commonly injured vertebra is the axis (C2). CSI diagnostics are based on prompt clinical assessment and utilization of radiological imaging. Certain patient groups, such as the elderly and patients with traumatic brain injury (TBI), are considered to be highly susceptible to CSI. CSI diagnostics remain challenging for clinical practitioners and failure to diagnose CSI in acute care may have serious consequences.

The aims of this thesis are 1) to define the trends in incidence and characteristics of fatally cervically injured patients in Finland; 2) to define the rate of errors in cervical spine injury diagnostics and to characterize patients who are most at risk of diagnostic errors and preventable adverse events (PAE); 3) to study the comorbidity of TBI and cervical spine fractures among head-injured patients in an emergency department (ED) setting; and 4) to study risk factors for cervical spine fractures and fracture distribution among head-injured patients treated in an ED.

Epidemiological data, and data on diagnostic errors and other adverse events (AE) were obtained from the death certificates of cervical spine-injured patients (n=2,041), that were issued in Finland between 1987 and 2010. Risk factors for cervical spine fractures in head-injured patients were evaluated from patients treated at the Tampere University Hospital´s ED between August 2010 and July 2012. The original ED sample included 3,023 consecutive patients who underwent head CT due to an acute head injury (HI).

In the nationwide, death certificate-based study, we found that the incidence of CSI increased between 1987 and 2010 from 16/million/year to 19/million/year. The mean age of patients with fatal CSI increased dramatically. Falls exceeded traffic accidents as the predominant cause of CSIs in 1998. Moreover, alcohol

contributed to a considerable number of CSIs. The frequency of diagnostic errors and PAEs increased slightly during the study period despite improvements in radiological services and advancements in medical care in general. Diagnostic errors were most commonly associated with high patient age and ground-level falls. In the ED setting (among patients with HI), those with CT positive TBI, high energy injury mechanism, high age, and facial fractures, had an increased risk of concurrent cervical spine fractures. The axis (C2) was the most commonly injured vertebra.

In conclusion, this thesis confirms the changing demographics in cervical spine trauma. The incidence of fatal CSI is not decreasing despite improved traffic safety and general health of people. Low-energy falls by elderly men have contributed most to the number of fatal CSIs in recent years. Alcohol is a major risk factor for fatal CSI especially among young men. CSI diagnostics continue to be challenging despite the wide availability of CT and magnetic resonance imaging. CT positive TBI and high-energy injury mechanism, as well as high age are risk factors for cervical spine fractures among HI patients. However, special consideration in cervical spine evaluation should be given to elderly patients who sustain a low energy trauma as most of the errors in CSI diagnostics occur to this subgroup.

TIIVISTELMÄ

Kaularankavamma voi johtaa pysyvään vammautumiseen tai kuolemaan. Väestöltään Suomen kaltaisissa maissa kaularankavamman vuosittainen ilmaantuvuus on noin 9-17/100,000 asukasta. Tarkasti ei tiedetä, kuinka moni kaularankavamman saaneista menehtyy ennen hoitoon pääsyä. Yleisimmät vammamekanismit ovat liikenneonnettomuudet ja kaatumisvammat. Yleisimmin vaurioituu kiertonikama (C2). Kaularankavamman diagnostiikka perustuu huolelliseen kliiniseen arvioon ja kuvantamistutkimuksiin. Kaularankavamman riski on suurentunut esimerkiksi iäkkäillä sekä potilailla, joilla todetaan samanaikainen tapaturmainen aivovamma. Kaularankavammojen diagnostiikka on edelleen haastavaa, ja voi epäonnistuessaan johtaa vakaviin seurauksiin.

Tämän tutkimuksen tavoitteena oli 1) määrittää kuolemaan johtavien kaularankavammojen ilmaantuvuus Suomessa sekä vammautuneiden erityispiirteet 2) selvittää diagnostisten virheiden ja ennaltaehkäistävien haittatapahtumien määrää ja kehitystä sekä määrittää minkä tyyppiset potilaat ovat suurimmassa riskissä näille tapahtumille 3) selvittää tapaturmaisen aivovamman ja kaularankamurtumien yhteyttä 4) selvittää kaularankamurtumille altistavia tekijöitä päävammapotilailla sekä määrittää tyypillisimmät kaularankamurtumat.

Epidemiologiset sekä diagnostisiin virheisiin ja haittatapahtumiin liittyvät tiedot kerättiin Suomessa laadituista kuolintodistuksista, joissa oli merkintä kaularankavammasta (2,041 kuolintapausta) vuosilta 1987–2010. Kaularankamurtumien riskitekijöitä päävammapotilailla tutkittiin potilaista (alkuperäinen potilasmäärä 3,023), joille oli tehty akuutin pään vamman vuoksi tietokonetomografia (TT) Tampereen yliopistollisen sairaalan ensiavussa elokuun 2010 ja heinäkuun 2012 välisenä aikana.

Koko maan kattavassa, kuolintodistuksiin perustuvassa tutkimuksessa oli löydöksenä kaularankavamman vuosittaisen ilmaantuvuuden nousu vuosien 1987 ja 2010 välillä arvosta 16, arvoon 19/miljoona henkilöä. Potilaiden keski-ikä nousi samoin huomattavasti. Vuoteen 1998 asti liikenneonnettomuudet olivat suurin kuolemaan johtavan kaularankavamman aiheuttaja, mutta siitä eteenpäin kaatumiset olivat suurin näiden vammojen aiheuttaja. Alkoholi oli mukana

monessa kuolemaan johtavassa kaularankavammassa. Diagnostisia virheitä ja estettävissä olevia haittatapahtumia sattui enemmän tarkastelujakson loppupuolella, huolimatta siitä, että radiologisten tutkimusten saatavuus ja yleinen terveydenhuollon taso on parantunut. Diagnostisia virheitä sattui eniten lääkäreille vanhuspotilaiden kohdalla, sekä niiden, joilla vammamekanismina oli vähäenerginen kaatuminen. Suurentunut kaularankamurtuman riski todettiin niillä ensiavussa pään vamman vuoksi tutkituilla potilailla, joilla oli korkeaenerginen vammamekanismi, korkea ikä, löydöksiä pään TT tutkimuksessa tai kasvomurtuma. Yleisimmin murtui kiertonikama (C2).

Tämä tutkimus vahvistaa käsitystä siitä, että kaularankavamman saaneiden potilaiden demografia on muuttunut ja että kaularankavamman ilmaantuvuus on nousussa huolimatta esimerkiksi liikenneturvallisuuden parantumisesta. Iäkkäiden miesten kaatumistapaturmat aiheuttavat nykyään suurimman osan kuolemaan johtavista kaularankavammoista. Alkoholi on erityisesti nuorten miesten keskuudessa yleinen vammautumiseen myötävaikuttava tekijä. Kaularankavammojen diagnosointi on vaikeaa huolimatta kuvantamistutkimusten (TT ja magneettikuvaus) parantuneesta saatavuudesta. Päävammapotilaiden TT-tutkimuksessa havaittava akuutti aivovamma, korkeaenerginen vammamekanismi ja potilaan korkea ikä lisäävät kaularankamurtuman todennäköisyyttä. Erityistä huolellisuutta tulisi noudattaa tutkittaessa iäkkäitä kaatumavammapotilaita, sillä suurin osa diagnostisista virheistä tapahtuu heidän kohdallaan.

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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following four original publications which are referred to in the text using Roman numerals I-IV. The original publications have been reprinted with the permission of the copyright holders. In addition, some previously unpublished data are included in the thesis.

I Thesleff, T., Niskakangas, T., Luoto T. M., Öhman, J., Ronkainen, A. (2016). Fatal cervical spine injuries: a Finnish nationwide register-based epidemiologic study on data from 1987 to 2010. Spine J. Aug;16(8):918-26.

II Thesleff, T., Niskakangas, T., Luoto, T. M., Iverson, G., Öhman, J., Ronkainen, A. (2017). Preventable Diagnostic Errors in Fatal Cervical Spine Injuries: A Nationwide Register-Based Study from 1987 to 2010. Spine J. in Press

III Thesleff, T., Kataja, A., Öhman, J., Luoto, T. M., (2017). Head Injuries and the Risk of Concurrent Cervical Spine Fractures. Acta Neurochirurgica. May;159(5):907-914.

IV Thesleff, T., Niskakangas, T., Öhman, J., Ronkainen, A., Luoto, T. M. Concurrent Cervical Spine Fractures in Patients with Acute Head Injuries – Risk Factors and Clinicoradiological Findings. Submitted for publication.

ABBREVIATIONS

AE	Adverse Event
AIS	ASIA Impairment Scale
ALL	Anterior Longitudinal Ligament
AS	Ankylosing Spondylitis
ASIA	American Spinal Injury Association
CCR	Canadian C-Spine Rule
CSI	Cervical Spine Injury
CT	Computed Tomography
CTA	Computed Tomography Angiography
CVJ	Craniovertebral junction
CI	Confidence Interval
C0	Occipital condyle
C1	First cervical vertebra (atlas)
C2	Second cervical vertebra (axis)
C3	Third cervical vertebra
C4	Fourth cervical vertebra
C5	Fifth cervical vertebra
C6	Sixth cervical vertebra
C7	Seventh cervical vertebra
DISH	Diffuse Idiopathic Skeletal Hyperostosis
DSA	Digital Subtraction Angiography
ED	Emergency Department
GCS	Glasgow Coma Scale
HI	Head Injury
ISS	Injury Severity Score
ICD-10	International Classification of Diseases 10^{th} revision
MRA	Magnetic Resonance Angiography
MRI	Magnetic Resonance Imaging
NEXUS	The National Emergency X-ray Utilization Study

OSF	Official Statistics of Finland
PAE	Preventable Adverse Event
PLL	Posterior longitudinal ligament
SCI	Spinal Cord Injury
SCIWORA	Spinal Cord Injury Without Radiological Abnormality
SD	Standard Deviation
SLIC	Subaxial Injury Classification
TBI	Traumatic Brain Injury
U.S.	United States
VAI	Vertebral Artery Injury
WHO	World Health Organization

1 INTRODUCTION

From diagnostics to definitive treatment, the management of cervical spine injuries (CSIs) continues to be a clinical challenge. Injury to cervical spine may be a minor distension or major injury leading to tetraplegia (impairment of function in all four limbs, trunk, and pelvic organs) or even death. In addition to the often detrimental impact on the individual patient and his/her family and surroundings, CSI causes substantial economic consequences in the form of direct and indirect costs (Baaj, Uribe et al. 2010, Krueger, Noonan et al. 2013). Approximately 2-7% of blunt trauma patients suffer a CSI (Milby, Halpern et al. 2008, Hasler, Exadaktylos et al. 2012, Sanchez, Waxman et al. 2005). The estimated whole population incidence of CSI, in countries with similar population demographics to Finland (e.g., Norway, Sweden, Canada), is about 9-17/100,000 (Fredø, Bakken et al. 2014, Brolin, von Holst 2002, Hu, Mustard et al. 1996). The reported incidence numbers do not include patients who succumbed prior to hospitalization.

As CSI is potentially preventable, it is of utmost importance to understand its epidemiological features in order to allocate preventive measures to high-risk groups. CSI occurs in all demographic categories, but incidence rates and other epidemiological features differ considerably depending on geographical and cultural differences (Yang, Ding et al. 2013, Gupta, Reeves 2009). The most typical trauma mechanisms in CSI are traffic accidents and falls (Leucht, Fischer et al. 2009, Clayton, Harris et al. 2012). Falls are common in the elderly, and they may sustain a CSI after a seemingly low-energy trauma, such as a ground-level fall (Wang, Coppola et al. 2013, Kannus, Palvanen et al. 2007). It is estimated that 30% of people aged 65 or older fall every year (Nevitt, Cummings et al. 1989, Hoidrup, Sorensen et al. 2003). The incidence of fall-related CSIs among elderly patients has increased during the past decades (Kannus, Palvanen et al. 2007). Patients aged 65 years or older have a relative risk for CSI twice that of younger trauma patients (Lowery, Wald et al. 2001, Goode, Young et al. 2014).

Failure to diagnose a CSI at the time of presentation may have disastrous consequences, with a high risk of neurological deterioration (Morris, McCoy 2004). Clinical examination is an essential component in CSI diagnostics, however, clinical prediction rules are not operable in certain circumstances such as among patients with decreased level of consciousness, for example. (Hoffman, Mower et al. 2000, Stiell, Wells et al. 2001).

Head injuries (HI) are one of the most common reasons for emergency department (ED) admissions (Thurman, Alverson et al. 1999, Corrigan, Selassie et al. 2010), and patients with HI and/or traumatic brain injury (TBI) comprise the largest group of patients seen in EDs where clinical examination alone is not sufficient to rule out CSI. To what extent head trauma severity is associated with concomitant CSIs is controversial (Gbaanador, Fruin et al. 1986, Hasler, Exadaktylos et al. 2012, Soicher, Demetriades 1991, Vahldiek, Thieme et al. 2017, Williams, Jehle et al. 1992). Furthermore, CSI diagnostics are especially challenging among elderly patients and it has been shown that clinical prediction rules as applied to elderly patients, have failed to predict injury (Denver, Shetty et al. 2015, Healey, Spilman et al. 2017, Lieberman, Webb 1994).

Assessment of spinal stability is essential, as the choice of treatment in each specific type of CSI is based on whether the injury is considered stable or not. The analysis of fractures is important in treatment planning. The axis (C2) is the most commonly injured cervical vertebra, followed by the C6 and C7 vertebrae (Pryputniewicz, Hadley 2010, Goldberg, Mueller et al. 2001). Among head-injured patients, the patterns and distribution of cervical spine fractures is not well known.

2 LITERATURE REVIEW

2.1 Anatomy of the cervical spine

In this chapter, a brief description of the anatomical features of the cervical spine is presented according to Williams and Warwick (Williams, Warwick 1980).

The cervical spine consists of seven vertebrae C1 – C7 and is a relatively complex anatomical structure. The atlas (C1) and the axis (C2) together with the occiput (C0) comprise the upper cervical spine whereas vertebrae C3 to C7 comprise the subaxial or lower cervical spine. The atlas, the first cervical vertebra supports the head (hence its name) by two ellipsoid shaped facet joints which are seated in two bulky lateral masses. It is a solid bone ring and differs from all other vertebrae in lacking a body. The two lateral masses are connected at the front by an anterior arch and posteriorly by a longer posterior arch. Transverse processes of the atlas are unusually long making them adequate levers for the muscles which aid in the rotation of the head (Figure 1). The axis is the pivot on which the atlas rotates (Figure 2). It is distinguished by a strong special structure called the odontoid process (Dens), which rises perpendicularly from the body. The odontoid process has articulation in the anterior surface with the atlas, and in the posterior surface, the transverse ligament of the atlas grooves the odontoid process. The axis also has two facet joints with the atlas and two with the vertebra C3. The pedicles of the axis are stout and the laminae that provide attachment to ligamenta flava are thicker than in any other cervical vertebra. The spinous process is powerful and takes the pull of several muscles. The transverse processes of the axis are small. Approximately 50 % of head rotation occurs at the atlanto-axial level and about 85 % of the whole head and neck movements come from skull-atlas-axis complex. Vertebrae C3 to C7 all have somewhat similar appearance and consist of a body, pedicles, lateral masses/ articular processes, laminae, transverse processes and a spinous process (Figure 3). The size of the vertebrae in the lower cervical spine increases from top to bottom. The most important stabilizing ligaments in the cervical spine are the anterior longitudinal ligament (ALL), the anterior atlanto-occipital membrane, the apical ligament, the paired alar ligaments, the cruciform ligament of the atlas, the posterior longitudinal ligament (PLL), the tectorial membrane (an upward extension of the PLL), the ligamentum flavum, the posterior atlanto-occipital membrane, the ligamentum nuchae, the interspinous ligaments, the intertransverse ligaments, and the articular capsules. Altogether, the cervical spine has 23 articulations: two C0/C1 facet joints, two C1/C2 facet joints and the odontoid process articulation with the C1 arch, and two facet joints plus an intervertebral disc in each of the six segments between C2/3 and C7/Th1. The spinal cord is situated in the vertebral canal and continues as the medulla oblongata at the level of the odontoid process. The spinal nerve roots exit the spinal canal via the intervertebral foramina except the first and second roots which exit the spinal canal posterior to the pedicles. The vertebral arteries arise from the subclavian arteries and supply blood to the posterior portion of the brain. They run upward through the foramina in the transverse processes of C6 (occasionally C7) to C1 to enter the skull through the foramen magnum.

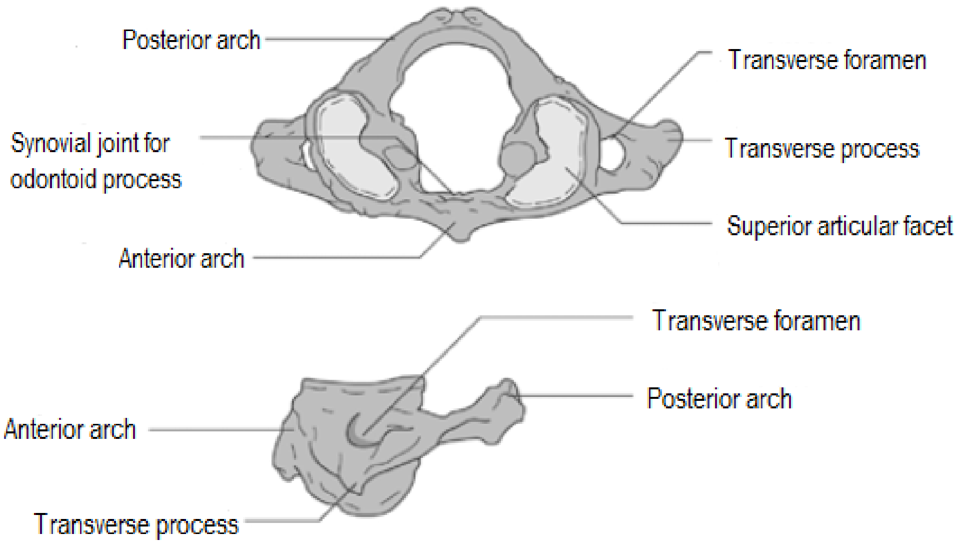


Figure 1. The atlas (C1) vertebra. Superior view (top) and lateral view (bottom). Modified from Gardner et al. (2005).

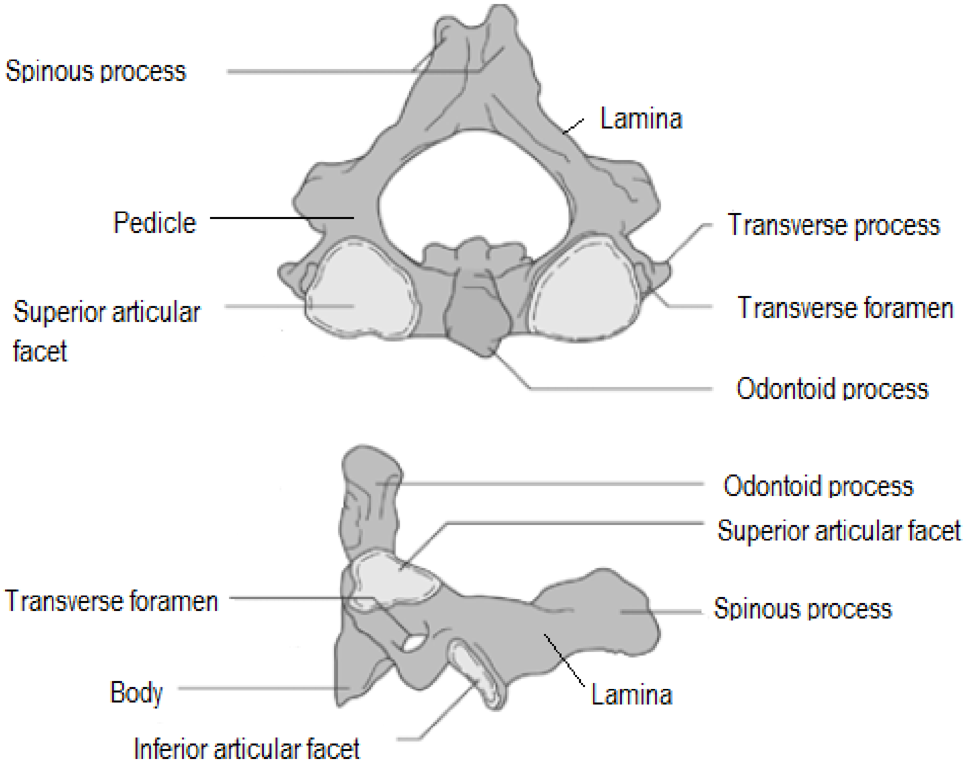


Figure 2. The axis (C2) vertebra. Superior view (top), and lateral view (bottom). Modified from Gardner et al. (2005).

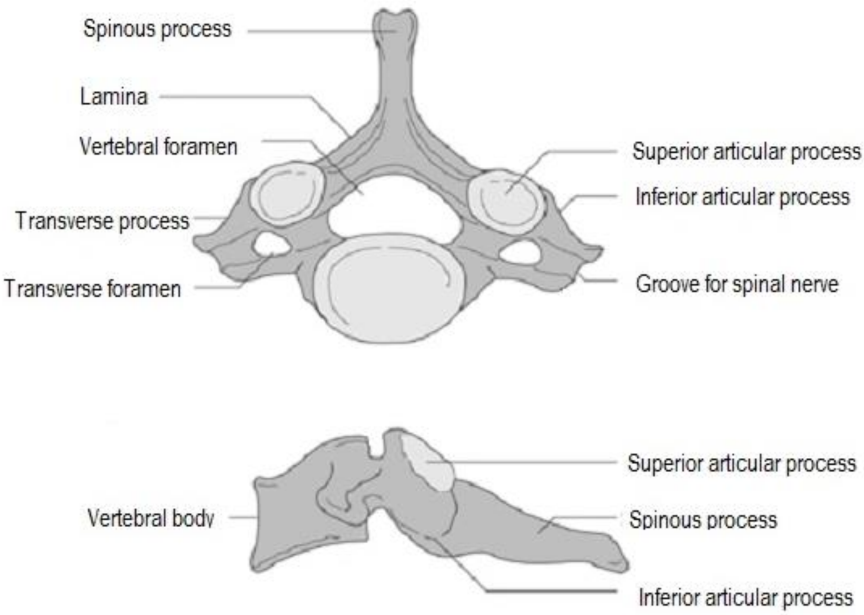


Figure 3. Typical subaxial vertebra. Superior view (top) and lateral view (bottom). Modified from Gardner et al. 2005.

2.2 Cervical spine injury (CSI) classification

In clinical practice, accurate and efficient diagnosis and management of CSIs is necessary to avoid further neurological deterioration. Assessment of spinal stability is essential as the choice of treatment in each specific type of CSI is based on whether the injury is considered stable or not. Since the classification system of cervical injuries by Böhler in 1951 (Hernigou 2016), many systems have been developed to categorize CSIs, but none of them has gained uniform acceptance among researchers or clinicians (Aebi, Nazarian 1987, Harris, Edeiken-Monroe et al. 1986, Allen, Ferguson et al. 1982). CSIs may be classified according to the level of injury (C0 –C7), mechanism of trauma (Allen, Ferguson et al. 1982, Harris, Edeiken-Monroe et al. 1986), morphology (Bohlman 1979), instability of the injury (Vaccaro, Koerner et al. 2016, Vaccaro, Hulbert et al. 2007), or neurological status (Vaccaro, Koerner et al. 2016, Vaccaro, Hulbert et al. 2007). An ideal classification system would be simple, reproducible and highlight the injury characteristics that are relevant for the care of the patient. However, due to the wide spectrum of injuries to the cervical spine, it is difficult to create a comprehensive classification system that is not cumbersome.

2.2.1 Craniovertebral junction (CVJ) injuries

Craniovertebral junction (CVJ) refers to osseous structures consisting of the occipital bone surrounding the foramen magnum, the atlas and the axis. The key ligaments and membranes in the area are the alar ligaments, the cruciform ligament, the apical ligament, the atlantoaxial accessory ligament, the capsular joints, the tectorial membrane, and the anterior and posterior atlanto-occipital membrane (Tubbs, Hallock et al. 2011). Ligaments and membranes in CVJ injuries have often been recognized but only recently (due to magnetic resonance imaging (MRI) and the increase in the knowledge of anatomical and biomechanical characteristics in the CVJ area) their role has been highlighted (Debernardi, D'Aliberti et al. 2014). Recent data emphasize the major role of the ligaments and membranes in CVJ injuries with a secondary function of osseous structures (Debernardi, D'Aliberti et al. 2014).

Established classification systems in CVJ injuries are based on bony injuries even though CVJ stability is largely based on ligamentous integrity. A CVJ injury may occur with subtle physical examination findings and can have tragic consequences if missed. Many quantitative parameters are classically used to identify a CVJ distraction injury (Bono, Vaccaro et al. 2007). However, it should be cautioned that craniometrics measurements may not exclude ligamentous instability (Roy, Miller et al. 2015).

2.2.2 Occipital condyle (C0) fractures

Occipital condyle fractures are relatively rare injuries. They are usually caused by high-energy trauma (Bolender, Cromwell et al. 1978, Anderson, Montesano 1988, Maserati, Stephens et al. 2009). They are difficult to identify in plain radiographs alone. However, due to the widespread use of CT in trauma evaluation, these injuries are encountered more frequently nowadays (Bloom, Neeman et al. 1997, Wasserberg, Bartlett 1995, Capuano, Costagliola et al. 2004).

They occur in 0.4-0.7% of all major trauma patients who survive to the emergency department and represent less than 2% of all cervical spine fractures (Goldberg, Mueller et al. 2001). In autopsy series, the incidence of C0 fractures has been reported to be as high as 4 % in fatal head injuries (Tuli, Tator et al. 1997). Anderson and Montesano (1988) were the first to classify occipital condyle fractures in three categories (Anderson, Montesano 1988). Types I and II are considered clinically stable. In Type III there is a fracture-avulsion of the occipital condyle by the alar ligament and it is considered potentially unstable (Anderson, Montesano 1988). The classification scheme by Tuli et al. (1997) broadened the definition of stability to include also the atlantoaxial joint. In the presence of atlanto-occipital misalignment, surgical stabilization is recommended (Maserati, Stephens et al. 2009).

2.2.3 Atlas (C1) fractures

Atlas fractures account for about 9-11% of all cervical fractures and they often occur in combination with axis (C2) fractures (Goldberg, Mueller et al. 2001, Matthiessen, Robinson 2015, Kakarla, Chang et al. 2010, Hadley, Dickman et al. 1988). Atlas fractures were first described by Jefferson in 1920 (Jefferson 1927, Jefferson 1919). The management of atlas fractures is largely dependent on the integrity of the transverse atlantal ligament and whether the fracture occurs in isolation or in combination with other cervical spine fractures (Dickman, Greene et al. 1996, Spence, Decker et al. 1970). The fracture may involve the anterior arch, the posterior arch, the lateral masses or a combination of these. The classic Jefferson fracture is a burst fracture with lateral displacement of the lateral masses (Kakarla, Chang et al. 2010). The most typical fracture type seen in clinical practice involves either the anterior or the posterior arch alone or a combination of these (Landells, Van Peteghem 1988, Goldberg, Mueller et al. 2001).

There is no single classification system to accommodate all fracture types seen in clinical situations. The stability of atlas fractures has been based on the integrity of the transverse atlantal ligament. Based on the results by Spence et al. it has been suggested that if the sum of lateral displacement of the lateral masses is 7 mm or more, the transverse ligament is probably torn (Spence, Decker et al. 1970). According to the classification by Dickman et al., Type I involves intraligamentous disruption and Type II involves avulsion of the ligament´s bony insertion (Dickman, Greene et al. 1996).

Atlanto-axial dislocation (C1/C2) may occur in three patterns and represents about 10 % of cervical spine dislocations (Goldberg, Mueller et al. 2001). In rotatory dislocation, one facet is dislocated anteriorly and the other posteriorly. Anterior dislocation is due to transverse ligament rupture or odontoid process fracture and posterior dislocation is due to anterior arch fracture of the atlas or odontoid process fracture. Rotatory dislocation is classified according to Fielding in four types based on severity (Fielding, Hawkins 1977). Type I injury may occur within physiological range of motion, Types II and III with ligament injuries and Type IV in conjunction with odontoid process insufficiency.

2.2.4 Axis (C2) fractures

Fractures to the axis (C2) are the most common CSIs (Pryputniewicz, Hadley 2010, Goldberg, Mueller et al. 2001). They account for approximately 20% of all cervical spine fractures and their incidence is especially high in older populations (Touger, Gennis et al. 2002, Daniels, Arthur et al. 2014). Axis fractures can be divided into three distinct injury patterns: odontoid fractures, hangman´s fractures and fractures of the body of the axis involving all other injuries to the C2 vertebra (Pryputniewicz, Hadley 2010).

Odontoid fractures are the most common axis fractures (Greene, Dickman et al. 1997, Goldberg, Mueller et al. 2001). The classification of odontoid fractures was first developed by Anderson and D´Alonzo in 1974 (Anderson, D'Alonzo 1974). Hadley et al. provided the widely accepted modification to the classification system which is based on the anatomical location of the fracture line (Hadley, Browner et al. 1988). A Type I fracture, which is an alar ligament distractive avulsion of the odontoid tip, is considered stable and accounts for only 1-3% of odontoid fractures (Anderson, D'Alonzo 1974, Greene, Dickman et al. 1997). A Type II fracture occurs at the odontoid base and is considered unstable. Approximately 50% to 60% of odontoid fractures are type II (Anderson, D'Alonzo 1974, Greene, Dickman et al. 1997). Type IIA is a comminuted odontoid base fracture with additional chip fracture fragments at the odontoid base and is considered highly unstable (Hadley, Browner et al. 1988). Only 5% of Type II fractures belong to the IIA subclass (Hadley, Browner et al. 1988). Type III fractures account for 36-42% of odontoid fractures and are characterized by a fracture line that extends downward into the cancellous portion of the body of the axis (Greene, Dickman et al. 1997, Goldberg, Mueller et al. 2001). Type III fractures are usually considered stable. In 2005, Grauer at al. proposed a modified and redefined classification system for Anderson and D´Alonzo Type II and III fractures in order to help in fracture management (Grauer, Shafi et al. 2005).

A hangman´s fracture i.e., a bilateral fracture of the axis pars interarticularis or traumatic spondylolisthesis of the axis was established as the main mechanism of instantaneous death following hanging by Wood-Jones in 1913 (Wood-Jones 1913, Rayes, Mittal et al. 2011). However, several earlier reports had already suggested fractures of the cervical spine as the cause of death following hanging (Haughton 1866, Paterson 1890). Several classification systems for hangman´s fractures co-exist (Francis, Fielding et al. 1981, Pepin, Hawkins 1981), but the one proposed by Effendi in 1981 has gained the widest acceptance (Effendi, Roy et al. 1981). In Type I, the fracture line goes through the pars interarticularis bilaterally with less than 3mm of displacement. A Type II fracture has displacement of more than 3mm and Type III an additional C2/3 facet joint displacement. In 1985, Levine and Edwards modified the Effendi classification (Levine, Edwards 1985). A hangman´s fracture is typically a hyperextension injury following traffic accidents and falls. It represents approximately 10-40 % of axis fractures (Goldberg, Mueller et al. 2001, Burke, Harris 1989). Effendi type I is the most frequent subtype (Effendi, Roy et al. 1981).

Axis body fractures are mixed fractures of the second cervical vertebra. They have been referred to by many names and labeled as axis body fractures, non-odontoid fractures, non-hangman´s fractures or miscellaneous fractures (including pedicle, superior articulating process, and transverse foramen) of the axis (Hadley, Dickman et al. 1989, Benzel, Hart et al. 1994). Their incidence varies depending on the classification. In the series of Greene et al., the incidence of miscellaneous fractures to the axis was 20% (Greene, Dickman et al. 1997).

2.2.5 C3-C7 fractures

Currently there is no universally accepted classification system for subaxial cervical spine fractures. In 1970, Holdsworth developed a classification based on mechanism of injury (Holdsworth 1970). In 1982, Allen and Ferguson proposed their classification based on the mechanism of injury including: compressive flexion, vertical compression, distractive flexion, compressive extension, distractive extension, and lateral flexion (Allen, Ferguson et al. 1982). Modifications to this system were done by Harris et al. (Harris, Edeiken-Monroe et al. 1986).

In the SLIC-system (Subaxial Injury Classification), developed by The Spine Trauma Study Group in 2007, injuries are characterized based on three main categories: injury morphology, disco-ligamentous complex integrity, and neurologic status (Vaccaro, Hulbert et al. 2007). Each of the categories is individually analyzed and given a score. The sum of the scores for all three categories is used for prognostication and management decision-making. However, among surgeons, the SLIC system has shown low reproducibility in treatment decision-making (Middendorp, Audige et al. 2013). In order to produce a classification system with higher interobserver and intraobserver reliability, the AOSpine subaxial cervical spine injury classification system has been developed (Vaccaro, Koerner et al. 2016), In the AOspine system, the following four classification criteria are used: injury morphology, facet injury, neurological status, and the presence of specific modifiers (posterior capsuloligamentous complex injury without complete disruption, critical disk herniation, stiffening/metabolic bone disease, and signs of vertebral artery injury).

CSI occurs most often in the subaxial spine, while the axis is the most commonly injured individual vertebra. C6 and C7 are the most frequently affected vertebrae (about 50 % of CSIs occur in the C5/6 and C6/7 area) and C3 or C4 get injured only rarely (Goldberg, Mueller et al. 2001). The dislocations or subluxations in the subaxial spine occur most often in the C5/6 and C6/7 interspaces (Goldberg, Mueller et al. 2001). The distribution of fractures by anatomical structure in blunt trauma patients by Goldberg et al. is as follows: vertebral body 29.9%, pedicle 5.9%, lateral mass / articular process 14.9%, lamina 16.4%, transverse process 9.2%, spinous process 20.8%, and other 2.9%.

2.2.6 Spinal cord injury (SCI)

About 10%–50% of CSI patients suffer a concomitant spinal cord injury (SCI) (Leucht, Fischer et al. 2009, Bohlman 1979), and a small proportion of patients suffer only a spinal nerve injury (Fredø, Bakken et al. 2014). The clinical severity of SCI depends on the spinal level and completeness of the injury. By definition, in complete injury, sacral sparing (either preservation of sensation in S4-5 dermatome or awareness of deep anal pressure or voluntary anal sphincter contraction) is lost. The American Spinal Injury Association (ASIA) Impairment Scale (AIS) designation is commonly applied for grading the degree of impairment (Kirshblum, Burns et al. 2011). An AIS grade A refers to a complete injury, an AIS B is a motor complete-sensory incomplete injury, AIS C and D are incomplete motor and sensory injuries and an AIS E represents normal motor and sensory functions at the time of examination.

MRI may show spinal cord edema, cord contusion, intramedullary hemorrhage, cord transection, soft tissue injury, spinal canal stenosis or disk herniation. Furthermore, the maximum spinal cord compression, maximum canal compromise and length of spinal cord lesion may be assessed. (Miyanji, Furlan et al. 2007). MRI findings of the spinal cord provide prognostic information regarding long-term outcomes in SCI patients (Flanders, Schaefer et al. 1990, Miyanji, Furlan et al. 2007). In addition to conventional MRI sequences, diffusion tensor imaging has been shown to be a quantitative and objective tool for assessing the state of the cervical spinal cord in patients with chronic SCI (Koskinen, Brander et al. 2013).

SCI may occur without the presence of a bony injury or dislocation in conventional three-view radiographic series or CT. The NEXUS-study reported a 3% incidence of SCI after the absence of traumatic findings in plain radiographs (Hendey, Wolfson et al. 2002). Kato et al. reported the incidence of cervical SCI without bony injury or dislocation (both plain radiographs and CTs were assessed) in up to 32% of all cervical SCI patients in Japan (Kato, Kimura et al. 2008). Cervical spondylosis, developmental narrowing of the spinal canal and disc herniation are well known risk factors for SCI without bony injury (Epstein, Epstein et al. 1980, Koyanagi, Iwasaki et al. 2000). SCIWORA (SCI without radiographic abnormality) is a term used for a blunt injury to the spinal cord without radiological findings (Pang 2004). The term was invented in the pre-MRI era and is nowadays seldom used, except for pediatric patients (Pang, Wilberger Jr 1982). The pediatric spine is physiologically hypermobile and therefore more at risk for this type of injury (typically children less than 8 years of age) (Pang 2004).

2.2.7 Vertebral Artery Injury (VAI)

A vertebral artery injury (VAI) may occur in conjunction with a CSI and cause additional morbidity and mortality. VAI is traditionally considered infrequent among CSI patients, but due to the heightened awareness of the condition and frequent use of CT angiography, the rate has increased dramatically. The incidence of VAI is reported from 24 to 48% among patients with a cervical fracture extending into the transverse foramen. (Parbhoo, Govender et al. 2001, Giacobetti, Vaccaro et al. 1997, Friedman, Flanders et al. 1995). Facet joint dislocations are also frequently associated with VAI with an average frequency of 35% (Inamasu, Guiot 2006). VAI types include dissection with or without an intimal flap or mural thrombus, pseudoaneurysm, occlusion, transection, and arterio-venous fistula (Inamasu, Guiot 2006). Dissection and occlusion are the two most frequent injury patterns.

2.3 Epidemiology and incidence of CSI

The reported incidence rates and other epidemiological features regarding CSI differ considerably depending on the population characteristics, geographical and cultural differences, and inclusion criteria and differences in data collection in individual studies. However, CSI occurs in patients in all demographic categories.

The incidence of CSI in a whole population setting is not well known. There are only a few studies on CSI incidence in the general population (Brolin, von Holst 2002, Hu, Mustard et al. 1996, Fredø, Bakken et al. 2014). A study from Sweden reported the incidence of cervical spine fractures to be 9.2/100,000/year in 1999 (Brolin, von Holst 2002). In the Canadian population between 1981 and 1984 Hu et al. found the incidence of all spine fractures to be 64/100,000/year. In that study, subgrouping into cervical, thoracic or lumbar fractures was performed for only 45% of the patients that were admitted to hospitals. The estimated incidence of cervical fractures was 12/100.000/year (Hu, Mustard et al. 1996). A recent study from Norway (2009-2012) reported the incidence of severe CSI to be 16.5/100,000/year and the incidence of traumatic cervical spine fractures 15.0/100,000/year (Fredø, Bakken et al. 2014).

CSI incidence in various subpopulations, such as trauma center patients, specific age groups, head injury patients, and patients with a specific injury mechanism has been studied widely (Brown, Brunn et al. 2001, Hills, Deane 1993, Michael, Guyot et al. 1989, Lowery, Wald et al. 2001, Thompson, Stiell et al. 2009). For example, Schoenfeld et al. studied cervical spine fractures in the U.S. military personnel and found an incidence of 29/100,000/year (Schoenfeld, Sielski et al. 2012).

In blunt trauma populations, the overall incidence of CSI has been reported to range from approximately 2 to 7%. Yanar et al. studied 8,401 pedestrians struck by an automobile in Los Angeles County and found the incidence of CSI to be 2.1% (Yanar, Demetriades et al. 2007). However, there was a substantial variation with age, ranging from 0.3% in the pediatric age group to 4.4% in the age group older than 65 years. A prospective cohort study conducted from October 1996 to April 1999 in Canada, involving almost nine thousand adults who presented to the emergency department with a blunt trauma to the head/neck, had stable vital signs and a Glasgow Coma Scale (GCS) score of 15, found the incidence of clinically significant CSI to be 1.7% (Stiell, Wells et al. 2001). In an emergency department sample from the U.S. involving blunt trauma patients, 7% had a CSI (Sanchez, Waxman et al. 2005). A meta-analysis by Milby et al. found that 3.7% of all trauma patients had a CSI (Milby, Halpern et al. 2008).

The reported incidence of CSI among patients with HI varies approximately from 4-8% (Holly, Kelly et al. 2002, Hills, Deane 1993, Williams, Jehle et al. 1992, Mulligan, Friedman et al. 2010, Michael, Guyot et al. 1989). The incidence depends on the population studied and classification of both HI and CSI. Table 1 shows a list of relevant publications on the association of HI and CSI.

The proportion of cervical fractures among all patients with a spine fracture also varies considerably. Nelson et al. conducted a national (U.S.) data bank study of more than 80,000 blunt trauma patients with at least one spine fracture. The relative incidences of cervical, thoracic and lumbar fractures were 41%, 37% and 43%, respectively (Nelson, Martin et al. 2013). In a trauma center study by Leucht et al., cervical fractures represented only 21% and lumbar fractures 50% of all spine fractures (Leucht, Fischer et al. 2009). According to Lenehan et al. 51% of spine injury patients had a cervical injury (Lenehan, Boran et al. 2009). A noncontiguous spinal injury is identified in 10-20% of patients with CSI (Miller, Brubacher et al. 2011, Sharma, Oswanski et al. 2007).

The published incidence of traumatic spinal cord injury (SCI) ranges between 10 and 83 per million/year in the developed world (Wyndaele, Wyndaele 2006, Sekhon, Fehlings 2001, Pickett, Campos-Benitez et al. 2006, Dahlberg, Kotila et al. 2005). The incidence of SCI in the U.S. is approximately 40 per million inhabitants per year, and in Finland according to a recent study by Koskinen et al. the incidence is 25 to 38 per million per year depending on the catchment area (Koskinen, Alen et al. 2014). The majority of SCIs occur in the cervical region. In the study by Koskinen et al., 70% of the traumatic SCI patients were tetraplegic and the incidence of traumatic cervical SCI would be 18 to 27 per million per year accordingly (Koskinen, Alen et al. 2014). In a Chinese study, 72% of SCIs were cervical (Ning, Yu et al. 2011), however, only 50% of the SCI patients in a Canadian study were cervical (Lenehan, Street et al. 2012). According to Sekhon and Fehlings, approximately 55% of acute SCI occurs in the cervical region (Sekhon, Fehlings 2001). In a study from Finland by Ahoniemi et al., 57% of the patients treated in the biggest national rehabilitation center between 1996 and 2005 were tetraplegic (Ahoniemi, Alaranta et al. 2008).

The number of patients with a CSI who succumb prior to hospitalization and hence remain out of most of the incidence studies is not well known. Previous reports have suggested that 21-24% of victims who die immediately or soon after a traffic accident have a serious injury to the cervical spine of which the majority affect the craniocervical junction (Alker, Oh et al. 1975, Bucholz, Burkhead et al. 1979).

Table 1. List of relevant publications on association of head injury (HI) and cervical spine injury (CSI). (Study I, reprinted with permission).

Publication	Study Type	Study Population	Key Findings
Bayless et al. (1987)	Single center, retrospective	228 significant blunt head trauma patients	Only 1.7% of the patients with a significant blunt head trauma had a CSI.
Fujii et al. (2013)	National trauma databank	550,313 trauma cases	Incidence of CSI in TBI patients was 8.6%. CSI incidence was significantly higher among TBI patients than among other trauma patients.
Gbaanador et al. (1986)	Trauma center, retrospective	406 patients with HI	CSI occurred in only 1.2% of HI cases. Acute cervical radiography was not efficacious and should not be routinely used in the emergency management of head trauma.
Hasler et al. (2012)	Multicenter trauma registry	250,584 major trauma patients	Incidence of CSI in all trauma patients was 3.5%. Patients with lowered GCS or systolic blood pressure, severe facial fractures, dangerous injury mechanism, male gender and/or age ≥ 35 years have an increased risk for CSI. HI was not an independent predictor of CSI.
Hills et al. (1993)*	Single center	8285 blunt trauma patients	CSI occurred in 4.5 % of HI patients. Patients with clinically significant head injury were at greater risk for CSI. Patients with a GCS ≤ 8 were at even greater risk (7.8%).
Holly et al. (2002)	2 centers, retrospective	447 consecutive moderate-severe head trauma patients	Incidence of CSI in head trauma patients was 5.4%. GCS ≤ 8 or motor vehicle accident were risk factors for CSI.
Michael et al. (1989)	Single center, retrospective	359 patients with HI and 92 patients with CSI	CSI occurred in 6% of head injured patients. Coincidence of head injury and CSI in comatose patients was estimated 2.4%. All seriously head injured patients should be treated as having concomitant CSI until proven otherwise.

Milby et al. (2008)	Review article	281,864 trauma patients	CSI occurred in 3.7% of all trauma patients and in 7.7% of unevaluable patients (distracting painful injury, intoxication or concomitant HI).
Mulligan et al. (2010)	Databank	1.3 million trauma patients	CSI occurred in 7.0% of head injuries. An effective identification protocol for CSI in case of HI is proposed.
Soicher et al. (1991)	Single center, prospective	260 patients from falls or traffic accidents with a significant HI	CSI occurred in 3.5 % of significant HI patients. No association between severity of HI and the incidence of CSI.
Tian et al. (2009)	Single center, prospective	1,026 comatose TBI patients	Incidence of CSI in comatose TBI patients was 6.9%. Patients with a low GCS, motorcycle accident as the mechanism of injury and with a skull base fracture had an increased risk for CSI.
Vahldiek et al. (2016)	3 centers, retrospective	1,342 minor blunt trauma patients	No association between HI and CSI. Only one patient had combined craniocervical injury.
Williams et al. (1992)	Single center, retrospective	5,021 trauma patients	CSI occurred in 4.8% of HI patients. No significant difference in CSI incidence between HI and non-HI patients. GCS < 14 associated with CSI in HI and non-HI patients.

TBI = traumatic brain injury; CSI = cervical spine injury; HI = head injury; GCS = Glasgow Coma Scale

*No full text available

2.4 Risk factors for CSI

2.4.1 Gender, age and injury mechanism

Male gender is a known risk factor for injuries in general and also for CSIs. The proportion of male patients is reported around 60-80% in many CSI studies (Hasler, Exadaktylos et al. 2012, Lowery, Wald et al. 2001, Clayton, Harris et al. 2012, Hoffman, Mower et al. 2000, Yang, Ding et al. 2013).

The number of patients with a CSI varies with age in bimodal fashion. Young adults and elderly people have the highest CSI incidence (Lowery, Wald et al. 2001). The former is mostly due to road traffic accidents by young males and the latter to ground level falls.

The causes of injury vary between countries, between regions within a country, and between urban and rural locations (Yang, Ding et al. 2013). Sports injuries, motor vehicle accidents and falls from a height have been described as risk factors for CSI by many authors (Thompson, Stiell et al. 2009, Leucht, Fischer et al. 2009, Hasler, Exadaktylos et al. 2012, Clayton, Harris et al. 2012, Lenehan, Boran et al. 2009). In recent years, the age distribution has shifted towards elderly people and the mechanism of injury from motor vehicle injuries to ground level falls.

2.4.2 Alcohol and drugs

Alcohol is a major risk factor for injuries in general and CSI is not an exception. In Finland, every third fatal injury happens under the influence of alcohol (Tiirikainen 2009). The rate of alcohol intoxicated patients in trauma centers worldwide ranges from approximately 20 to over 40% (Jurkovich, Rivara et al. 1992). Alcohol use at the time of injury associates especially with cervical SCI as compared to lower spinal levels (Garrison, Clifford et al. 2004).

Non-prescription drugs increase the risk for traumatic injuries, though in Finland, they are not as commonly used as alcohol. However, in recent years their use has increased. For example, a Finnish study showed that between 1977 and 2007, driving under influence of non-prescription drugs increased manifold

(Ojaniemi, Lintonen et al. 2009). In addition to increasing the probability of an accident, alcohol and other drugs can decrease the patient's ability to feel pain. Intoxicated patients with a CSI may report no tenderness in the neck even with a significant injury.

2.4.3 Head injury

Sir Geoffrey Jefferson is considered to be the first person to report the coincidence of head trauma and CSI (Jefferson 1927). He observed that any vertical force directed to the vertex of the skull may result in the fracture of the atlas. Since then, several investigators have studied the relationship between HI and CSI with varying results. Table 1 summarizes relevant publications on the association between HI and CSI. This association appears logical assuming that forces applied to the face or head will be transmitted to the cervical spine and result in injury. Foster et al. suggested that "all head and neck trauma patients should be considered to have a cervical spine injury until proven otherwise" (Foster, Maisel et al. 1981). However, there are multiple studies that did not find this association between HI and CSI (Table 1). One theory is that the head and face may act as a cushion and buffer, dissipating the energy that would otherwise be transferred to the cervical spine, resulting in a lower risk of CSI. Moreover, CSIs may nowadays be more commonly associated with inertial differences in the head and torso, as opposed to transmitted compression forces from head or facial trauma. Increased use of safety features such as seat belts and airbags may have influenced the risk of HI-related CSI.

2.4.4 Ankylosing spinal disorders

The most common ankylosing spinal disorders are ankylosing spondylitis (AS, also known as Bechterew disease) and diffuse idiopathic skeletal hyperostosis (DISH, also known as Forestier disease) (Hartmann, Tschugg et al. 2017). AS is a chronic systemic and inflammatory rheumatic disease with a reported prevalence of up to 1.4 % (Braun, Sieper 2007). It mainly affects males. The etiology of DISH is still unknown but there is strong association with obesity, type 2 diabetes and high age (Weinfeld, Olson et al. 1997, Denko, Malemud 2006). The prevalence is estimated at between 3 and 25% (Hartmann, Tschugg et al. 2017). The condition is more common in men and prevalence peaks in the 60-

to 69 - year old age group (Kim, Choi et al. 2004). Both of the disorders lead to progressive ossification of the spinal column which makes the spine inflexible and highly susceptible to trauma even after low-energy impacts (Caron, Bransford et al. 2010). The spinal level most often injured in these patients is cervical. The diagnosis of cervical spine fracture in patients with ankylosing spinal disorders is often delayed and secondary deterioration after misdiagnosis of a fracture is a frequent problem with these conditions (Westerveld, Verlaan et al. 2009, Westerveld, van Bemmel et al. 2014).

2.4.5 Other risk factors

Several studies support a relationship between facial injuries and cervical spine trauma, with some reporting an incidence as high as 19% (Lewis, Manson et al. 1985, Mukherjee, Abhinav et al. 2015). Pelvic fracture especially when in conjunction with HI associates with CSI and probably reflects the high-energy injury mechanism in general (Clayton, Harris et al. 2012). High Injury Severity Score (ISS) and multiple extremity fractures are also reported to associate with CSI as is a decreased GCS score (Hasler, Exadaktylos et al. 2012, Clayton, Harris et al. 2012, Holly, Kelly et al. 2002, Hanson, Blackmore et al. 2000, Hills, Deane 1993). Moreover, clavicular injury has been found to associate with a CSI (Williams, Jehle et al. 1992). Degenerative changes and osteoporosis predispose to CSIs (typically odontoid process fractures), which are common among the elderly after low energy injuries (Kaesmacher, Schweizer et al. 2017, Watanabe, Sakai et al. 2014).

2.5 CSI diagnostics

Cervical spine clearance after blunt trauma is defined as accurately confirming the absence of a cervical spine injury (Anderson, Gugala et al. 2010, Richards 2005). The clearance of the cervical spine in trauma patients is difficult, time-consuming, and costly (Anderson, Gugala et al. 2010). The objective of cervical spine clearance is to establish that an injury does not exist. Failure to diagnose a CSI at the time of presentation can have disastrous consequences, with a high risk for neurological deterioration (Morris, McCoy 2004). Immobilization in a cervical collar should be initiated at the scene of injury and maintained until a directed examination is performed during the secondary evaluation (Schmidt, Gahr et al. 2009). However, cervical spine immobilization is not without consequences and should be kept in minimum (Greenbaum, Walters et al. 2009, Karason, Reynisson et al. 2014).

2.5.1 Clinical evaluation

Clinical examination is an essential component of the cervical spine clearance process. It includes a review of the history with regard to the injury mechanism and other relevant information (e.g., transient motor or sensory changes may indicate significant spinal pathology, and when noted requires radiographic assessment), identification of pain or tenderness in the head, neck or thoracolumbar spine or any neurologic changes of sensation or muscle strength in the trunk or extremities (Anderson, Gugala et al. 2010). Published, Level I evidence shows that asymptomatic, alert, neurologically intact patients do not need further imaging to declare the cervical spine clear (Hoffman, Mower et al. 2000, Stiell, Wells et al. 2001, Anderson, Muchow et al. 2010). The NEXUS (National Emergency X-Radiography Utilization Study Group) method uses specific criteria to identify the low-risk patient who can be cleared clinically without imaging. All of the five following criteria must be met for a patient to be considered low-risk: (i) an awake, alert patient; (ii) no history, signs, or laboratory evidence of intoxication; (iii) no distracting injury; (iv) no cervical spine pain or midline tenderness; and (v) no neurologic signs or symptoms (Hoffman, Mower et al. 2000). The sensitivity of the NEXUS method is excellent – 99.0% for all cervical injuries and 99.6% for significant CSI. Due to low specificity (12.9%), many potentially unnecessary radiographs are taken.

An alternative to the NEXUS protocol is the Canadian C-Spine Rule (Stiell, Wells et al. 2001). This rule applies to awake, non-intoxicated patients with a GCS score of 15 and identifies those who require radiographs by answering three questions. First, is the patient high-risk enough that radiographs are required? (Risk factors include: age >65 years, reports of paresthesia, and a dangerous mechanism of injury, for example, a fall from a height >1 m or five stairs, axial load to the head, and a high-speed [>100 km/h] automobile, motorcycle, recreational vehicle, or bicycle accident). Second, is there a low risk factor that would allow the safe assessment of range of motion? Examples of such a factor are a simple rear-end motor vehicle crash, a patient who has already sat upright in the emergency department or was ambulatory at any time, a delay in the onset of pain, and an absence of tenderness. Third, can the patient actively rotate the head 45° to the right and left without pain? A patient who is not at high risk and can safely perform the rotation test can be cleared clinically without radiographs. The sensitivity of the Canadian C-Spine rule is reported to be 100% and the specificity to be 42.5% (Stiell, Wells et al. 2001).

In a separate study, Stiell at al. found that in applying the Canadian C-Spine rule instead of NEXUS criteria, 10 % fewer cases would have required radiographs (Stiell, Clement et al. 2003). In a meta-analysis by Tontz et al. totaling more than 63,000 patients, including three NEXUS, two Canadian C-Spine Rule, and nine institutional protocols, the overall sensitivity based on a random effects model was 98.1%, with specificity being 35.0%. Of 28 missed injuries, only 2 were deemed significant but none was associated with neurological deterioration (Tontz, Anderson et al. 2006).

2.5.2 Cervical spine imaging

Cervical spine imaging is a key element in addition to history and physical examination in trauma patients who are suspected to have a CSI. A patient who has neck pain, midline tenderness, or neurological symptoms requires radiographic imaging. Imaging options are plain radiography, flexion-extension radiography, CT and MRI. If vascular injury is suspected, angiographic studies are needed.

Plain radiographs are usually not recommended in the acute phase evaluation of CSI, because even with the best possible technique, they underestimate the amount of traumatic spine injury and detect only 52-85% of fractures, even when three views are obtained (Gale, Gracias et al. 2005, Holmes, Akkinepalli 2005, Hadley, Walters 2013). However, plain radiographs are often used in the follow-up evaluation of possible unstable injuries. The use of flexion-extension radiographs in the acute setting is also controversial and carries a risk of causing additional neurological damage, hence its use is best left for the subacute evaluation when there is a specific clinical concern. (Anglen, Metzler et al. 2002, Pollack, Hendey et al. 2001, Knopp, Parker et al. 2001).

Computed tomography (CT) has supplemented plain radiography in CSI screening and is the primary imaging modality for evaluating patients with a blunt CSI. It detects 97-100 % of fractures to the cervical spine (Shah, Ross 2016, Hadley, Walters 2013, Brown, Antevil et al. 2005). The imaging must include axial scans from the occiput to the first thoracic vertebra with coronal and sagittal reconstructions.

MRI is superior to CT for the detection of neural, ligamentous, and disc injuries and is primarily employed for the patient who presents with a neurological deficit, or when ligamentous injury is suspected (Pourtaheri, Emami et al. 2014, Schoenfeld, Bono et al. 2010, Muchow, Resnick et al. 2008). Nevertheless, there is significant heterogeneity in the literature regarding the use of MRI after a negative CT to rule out ligament injury (Malhotra, Wu et al. 2017). The drawbacks of MRI are that it requires extensive time to perform, it interferes with patient´s monitoring equipment, the inability to use it in hemodynamically unstable patients, and its high cost (Dunham, Brocker et al. 2008).

Angiographic studies; computed tomography angiography (CTA), magnetic resonance angiography (MRA), and digital subtraction angiography (DSA) are utilized to detect vessel injuries in CSI patients. DSA is the gold standard for detecting VAIs and is the primary imaging modality particularly when endovascular treatment is considered. According to level I evidence, CTA is an alternative to DSA and is usually the primary imaging modality, not least because it is readily available (Utter, Hollingworth et al. 2006). The advantage of MRA is that it does not use contrast agents and it may be obtained in conjunction with MRI (Hadley, Walters 2013).

Patients with a decreased level of consciousness remain a group in which the clearance of the cervical spine remains controversial and unresolved. The risks of an occult CSI must be weighed against the potential harm caused by prolonged cervical immobilization. In addition to general comfort issues, prolonged immobilization may lead to complications such as increased intracranial pressure for those with closed head injury, predisposition to pressure sore development, and ventilator-associated pneumonias (Morris, McCoy 2004, Greenbaum, Walters et al. 2009). Trauma centers show marked variation in spine clearance protocols among patients with decreased level of consciousness. It is not clear to what extent CT alone can direct clearance of the cervical spine. Several investigations have advocated CT as a single modality capable of detecting all significant CSIs (Tomycz, Chew et al. 2008, Schuster, Waxman et al. 2005, Como, Thompson et al. 2007). However, a huge body of research suggest that MRI of the cervical spine is a necessary adjunct in the evaluation of patients with decreased levels of consciousness. (Menaker, Philp et al. 2008, Stassen, Williams et al. 2006, Pourtaheri, Emami et al. 2014, Muchow, Resnick et al. 2008).

2.6 Consequences of CSI

Injury to the cervical spine may be a minor distension or major injury leading to tetraplegia (impairment of function in all four limbs, trunk, and pelvic organs) or even death. SCI, in addition to disturbing motor and sensory functions below the level of injury, impairs somatic and autonomic nervous system, control of blood vessels, heart, respiratory tract, sweat glands, bowel, urinary bladder, and sexual organs (Krassioukov, Biering-Sorensen et al. 2012). Early death following cervical SCI is usually due to respiratory failure and/or cardiovascular dysfunction (Lemons, Wagner 1994). Complete SCI at or above the C3 spinal level causes immediate death (if mechanical ventilation is not started immediately) due to disruption of innervation to the diaphragm and intercostal muscles. In the acute phase of SCI, patients are prone to spinal shock (flaccid paralysis and areflexia) and neurogenic shock (i.e., bradyarrhythmias, atrioventricular conduction block and hypotension) (Ditunno, Little et al. 2004, Piepmeier, Lehmann et al. 1985). The incidence of neurogenic shock, depending on the level and severity of injury, is reported up to 100% among patients with cervical SCI and contributes to poor outcomes (Piepmeier, Lehmann et al. 1985).

SCI predisposes patients to various secondary complications throughout life. In the past, renal failure and other urinary tract complications were the primary causes of death of patients with long-standing SCI. Due to advances in medical practice, the causes of death of patients with chronic SCI are approaching those of the general population. However, increased mortality in this patient group is still present (Hagen, Eide et al. 2010). Cardiovascular, and respiratory diseases together with infections are the leading causes of death of the chronic SCI population (DeVivo, Krause et al. 1999, Branco, Cardenas et al. 2007). Dysphagia and aspiration are common in patients with cervical SCI and contribute to the development of respiratory dysfunction and pneumonia (Shin, Yoo et al. 2011, Jackson, Groomes 1994, Ihalainen, Rinta-Kiikka et al. 2017b, Ihalainen, Rinta-Kiikka et al. 2017a).

In addition to often detrimental consequences for the individual patient, CSI is also a major economic burden for society (Kukreja, Kalakoti et al. 2015, Daniels, Arthur et al. 2014, Baaj, Uribe et al. 2010). In Canada, the estimated economic life-time burden of a patient with a complete tetraplegia was three million dollars (Krueger, Noonan et al. 2013). It is estimated that the increase in the economic burden today is attributable to improved life expectancy in the SCI population and increase in costs of care after SCI (Cao, Chen et al. 2011). Moreover, the costs of patients with CSI who do not have a combined SCI have increased during the last few years (Baaj, Uribe et al. 2010). This is probably due to an increase in the incidence of these injuries especially among elderly patients. Due to more complicated hospital stays, longer hospitalizations, and higher rates of inpatient facility care after hospital admission, older patients seem to have a higher propensity for greater health care resource utilization (Kukreja, Kalakoti et al. 2015, Baaj, Uribe et al. 2010).

Even though injuries to vertebral arteries often remain clinically occult, a small percentage of patients may suffer devastating neurological complications due to posterior circulation infracts (Inamasu, Guiot 2006).

2.7 Treatment of CSI

The goal in CSI treatment is to provide a stable and painless spine together with the best possible neurological recovery (Lauweryns 2010). The chosen treatment strategy of an individual patient is affected by multiple factors. For example, the type of injury, neurological status of the patient, probability of vertebra dislocation, the patient's body habitus and compliance to the treatment should all be taken into account. Although a multitude of guidelines for CSI treatment are available, there are still several controversies in how to treat CSI patients with or without SCI. The choice of one modality over another should be made on an individual basis. After the diagnosis of CSI, the short and long-term management should be determined. Long-term management is dependent on the location and pattern of the injury. In the short-term, continued immobilization is usually necessary to prevent further injury (Gardner, Grannum et al. 2005).

Operative treatment was given for 18-27% of patients with a CSI in Norway (Fredo, Rizvi et al. 2012). Injury to the cervical spine increases mortality and morbidity even without the presence of an SCI (Golob, Claridge et al. 2008, Bohlman 1979, Harris, Reichmann et al. 2010, Fredø, Bakken et al. 2014). The risk of complications in CSI treatment depends on the injury itself, the pre-injury characteristics of the patient and the chosen treatment method. Operative treatment of CSIs carries well documented risks (Fredø, Rizvi et al. 2016, Leckie, Yoon et al. 2016), but conservative treatment with cervical collars or halovest devices are not without complications either (Longo, Denaro et al. 2010, Butler, Dolan et al. 2010). Conservative treatment can be initially administered and can serve as an adjunct to surgery, or even be the definitive treatment. Supine skull traction is seldom used, but in some cases, such as facet subluxation or dislocation and burst-type fractures, it may be employed in the initial phase.

Surgical treatment of unstable CSIs usually allows earlier mobilization of the patient and shortens the primary hospital stay. According to the individual patient and injury type, surgery can be performed in numerous ways. Common upper cervical spine procedures include for example anterior odontoid screw fixation, posterior C1-C2 fixation, and occipito-cervical fixation. In the subaxial spine, various methods exist also for anterior and posterior fixation with different kinds of screws, rods, plates and wires. In patients with ankylosing spinal disorders, fractures typically involve the anterior, middle, and posterior columns with high dislocation probability and therefore surgical fixation is often mandatory. In these cases, a posterior or circumferential approach is recommended due to the high failure rate with anterior-only surgeries(Ma, Wang et al. 2015, Hartmann, Tschugg et al. 2017).

2.8 Adverse events

An adverse event (AE) is usually defined as an unintended injury or complication, caused by health care management rather than the patient's underlying disease (Brennan, Leape et al. 1991). Regarding in-hospital AEs, health care management consists of actions of individual hospital staff as well as the broader systems and care processes, and includes both acts of omission (failure to diagnose or treat) and acts of commission (incorrect diagnosis or treatment, or poor performance) (Baker, Norton et al. 2004). AEs result in prolonged hospital stays, disability at the time of discharge, or death (Thomas, Studdert et al. 2000, Wilson, Runciman et al. 1995). In general, in-hospital AEs occur in approximately 10% of admitted patients, and about half of the AEs are considered preventable (preventable adverse event = PAE) (de Vries, Ramrattan et al. 2008, Soop, Fryksmark et al. 2009). In surgical and orthopedic care, the rate of AEs is considered even higher (up to 30%) and the majority are considered preventable (Merten, Johannesma et al. 2015, Rutberg, Borgstedt-Risberg et al. 2016). In-hospital AEs are lethal in about 7% of cases (de Vries, Ramrattan et al. 2008). Aside from the direct harm for the patient, AEs are a massive financial burden on society (Thomas, Studdert et al. 1999).

2.8.1 Diagnostic errors

Diagnostic AEs are mostly preventable and occur due to human failure (the main causes being mistakes due to a lack of knowledge and information transfer problems) in the majority of cases (Zwaan, de Bruijne et al. 2010). The mortality rate for diagnostic AEs is higher than for other AEs (Zwaan, de Bruijne et al. 2010). Diagnostic errors occur in every medical specialty and some of these errors lead to patient harm, that is, diagnostic AEs (Graber 2013). The error rate in clinical medicine is estimated at 5-15% (Berner, Graber 2008, Schwartz, Elstein 2008). The ED is an arena which requires complex decision-making in settings of above-average uncertainty and stress. Therefore, ED physicians are especially prone to diagnostic errors (Guly 2001). The patient groups most at risk of diagnostic errors are those admitted to a hospital in an emergency setting (Zwaan, de Bruijne et al. 2010). The error rate in perceptual specialties such as radiology or pathology is considered to be substantially lower than in clinical medicine (FitzGerald 2005, Kronz, Westra et al. 1999).

Historically, in the era of plain roentgenograms, misdiagnosis of a CSI was estimated in up to one-third of cases (Reid, Henderson et al. 1987, Davis, Phreaner et al. 1993, Platzer, Hauswirth et al. 2006). Currently, in the CT era, the rate of misdiagnosis is reported to range from 0 to 5% (Platzer, Hauswirth et al. 2006, Patel, Humble et al. 2015). A failure to identify a CSI is considered a diagnostic error. The reasons for diagnostic errors in CSIs are various. A successful cervical spine clearance is highly dependent on the appropriate utilization of radiographic studies (Greenbaum, Walters et al. 2009, Zakrison, Williams 2016). The ordering of inadequate, improper or non-sufficient radiographs is one issue (Davis, Phreaner et al. 1993, Lekovic, Harrington 2007), while scan misinterpretation (or non-reading) is another. It has been shown that if radiological images are interpreted by ED physicians instead of trained radiologists, clinically important CSIs are not sufficiently identified. (Berner, Graber 2008, Van Zyl, Bilbey et al. 2014).

Failure to consider the correct diagnosis as a possibility plays a significant role in diagnostics in general (Ely, Graber et al. 2011) as well as among CSI patients (Lieberman, Webb 1994). Clinical decision rules (e.g. NEXUS and CCR rules) have been developed to assist with deciding which patients require cervical spine imaging among alert and examinable patients (Hoffman, Wolfson et al. 1998, Stiell, Wells et al. 2001, Stiell, Clement et al. 2003). However, these criteria, as applied to elderly patients, have been reported to fail to predict injury in some cases (Denver, Shetty et al. 2015, Healey, Spilman et al. 2017). Furthermore, it is difficult to select patients who need additional imaging (e.g. MRI) after CT to rule out significant ligament injuries (Malhotra, Wu et al. 2017).

3 AIMS OF THE STUDY

1. CSI EPIDEMIOLOGY

   To determine the trends in the incidence and the characteristics of fatally cervical spine injured victims in Finland (Study I).

2. DIAGNOSTIC ERRORS

   To assess the rate and trend in incidence of errors in CSI diagnostics in Finland and to define factors predisposing to diagnostic errors (Study II).

3. COMORBIDITY OF HEAD INJURY AND CSI

   To study the comorbidity of TBI and cervical spine fractures among head-injured patients in an ED setting (Study III).

4. RISK FACTORS FOR CSI

   To study risk factors for cervical spine fractures, and fracture distribution among head-injured patients treated in an ED (Study IV).

4 MATERIALS AND METHODS

4.1 Study design and ethical aspects

The study design of Studies I and II is retrospective and is based on the data of death certificates issued in Finland between 1987 and 2010. The death certificates for the study were obtained from the Official-Cause-of Death register, which is coordinated by Statistics Finland (Official Statistics of Finland).

Studies III and IV are a part of the broader Tampere Traumatic Head and Brain Injury Study which includes all consecutive patients with HI who underwent a head CT at Tampere University Hospital ED between August 2010 and July 2012. All the data are retrospectively recorded in a separate HI registry. Ethical approval for the studies was obtained from the Ethical Committee of Pirkanmaa Hospital District, Finland (codes: R12215 and R10027).

4.2 Subjects in Studies I and II

4.2.1 The official cause of death register

Subjects for Studies I and II were obtained from the official Cause-of-Death register which is coordinated by Statistics Finland (Official Statistics of Finland). Statistics Finland maintains an archive of death certificates which includes all death certificates issued in Finland since 1936. The annual register covers all persons whose domicile is in Finland and who die during the calendar year in Finland or abroad. In Finland, the way to determine the cause of death of the deceased is defined in the law (1973/459) (Official Statistics of Finland 2015 b). Death certificates are issued by the physician establishing the death. If an autopsy is needed for determining the cause of death, a forensic pathologist will issue the death certificate. The death certificate is sent to the National Institute for Health and Welfare where a forensic pathologist verifies the correctness of each certificate, which is then sent on to Statistics Finland (Official Statistics of Finland 2015 b). The Finnish official Cause-of-Death statistics are, in practice, 100% complete and therefore a very reliable source of research data (Official Statistics of Finland 2015 b).

4.2.2 Death certification and medicolegal autopsies

The death certificate form is confirmed by the Ministry of Social Affairs and Health (Appendix). It is a document that among other information includes: (i) name, (ii) date of birth, (iii) date of death, (iv) municipality, (v) immediate cause of death, (vi) intermediate cause of death, (vii) main cause of death, (viii) related cause of death, (ix) manner of death, (x) place of the possible accident, (xi) place of death, (xii) narrative of the path to death, and (xiii) type of death certification.

According to Finnish legislation, a medicolegal autopsy should be performed in the following circumstances: when death is caused or suspected to be caused by (i) a crime, (ii) a suicide, (iii) an accident, (iv) poisoning, (v) an occupational disease, or (vi) medical treatment, or when death has (vii) not been caused by a disease, or when (viii) during the last illness, the deceased had not been treated by a doctor within 3 months, or when (ix) the death was otherwise unexpected.

In Finland, medicolegal autopsies are performed in up to 87.2% of all unintentional injury-related deaths, 98.3% of homicides, and 99.5% of suicides, which in part results in highly controlled and comprehensive national mortality statistics. In Finland, the number of performed medicolegal autopsies has been considerably higher than in many other developed countries (Lunetta, Lounamaa et al. 2007).

4.3 Subjects in Studies III and IV

4.3.1 Tampere Traumatic Head and Brain Injury Study

Subjects for Studies III and IV are derived from the Tampere Traumatic Head and Brain Injury Study that includes all consecutive patients (n=3,023) with HI who underwent head CT at Tampere University Hospital's ED between August 2010 and July 2012. The patients in the registry are prospectively enrolled from the ED and the data are retrospectively recorded.

In the ED, an emergency non-contrast head CT scan was performed as per Scandinavian guidelines for all patients (Ingebrigtsen, Romner et al. 2000), using a 64-row CT scanner (Lightspeed VCT; GE, Wisconsin, USA). In a non-on-call setting, all head CT scans were analyzed and systematically coded by two neuroradiologists using a structured data collection form.

Cervical CT was performed primarily according to NEXUS recommendations (Hoffman, Wolfson et al. 1998). On arrival, polytrauma patients underwent whole-body CT (comprising cervical spine) according to international recommendations (Blackmore, Emerson et al. 1999, Hessmann, Hofmann et al. 2006, Linsenmaier, Krotz et al. 2002, Schmidt, Gahr et al. 2009)

4.4 Methods

4.4.1 Data collection from death certificates (Studies I and II)

From Statistics Finland, all death certificates (n=2,041) between 1987 and 2010 containing CSI as immediate, intermediate, main, or related cause of death were obtained. During the study period, both the International Classification of Diseases (ICD)-9 and the ICD-10 codes were in use. In our study, CSI was defined as an injury to the cervical spine, including (i) fracture, (ii) dislocation, (iii) fracture with spinal cord injury, (iv) isolated spinal cord injury, or (v) a combination of the aforementioned.

The death certificates were thoroughly reviewed by the author (T.T.) to gather information on diagnosis (ICD codes), gender, age, time of injury, place of injury, time between injury and death, cause of death, type of injury, alcohol and drug consumption at the time of injury, type of death certification, presence of spinal cord injury, and rough level of cervical injury. Injuries at cervical levels C0-C2 were regarded as high injuries and injuries at levels C3-C7 as low injuries. In cases where the level was undetermined or the injury consisted of multiple levels, they were considered as low injuries. Substance abuse was considered positive if it was mentioned in the death certificate regardless of the method of affirmation.

4.4.2 Data collection from death certificates for diagnostic error study (Study II)

For Study II, all death certificates in which the date of death was later than the date of injury (n=744, 36.5%), were selected for further analysis. By doing this selection, we excluded people who, in the majority of cases, succumbed at the accident scene and therefore had a minor chance for PAE. The death reports of those who survived at least until the next day were thoroughly re-examined to detect reports with a suspicion of any kind of PAE. Preventability was defined as care that fell below the level of expected performance for practitioners or systems at the time of the PAE. If the death report did not provide enough information for a solid conclusion, it was considered as non-PAE or PAE undetermined. PAEs were categorized into two groups, namely diagnostic errors and other errors. Errors were further divided in six subcategories. Place of PAE occurrence was collected. If more than one PAE was detected for an individual patient, only the most severe one was coded.

4.4.3 Data collection from Tampere Traumatic Head and Brain Injury Study registry (Studies III and IV)

The medical records of all patients in the Tampere Traumatic Head and Brain Injury Study registry (n=3,023) were reviewed in detail to select those individuals whose cervical spine was CT-imaged due to a clinical suspicion of a CSI within one week after primary head CT. A total of 1,091 (36%) cervical spine CT-imaged patients were identified and included in the study. The majority of the patients (97%, n=1,053) were cervically CT-imaged within 24 hours after primary head CT.

Data collected from the registry includes subject and injury-related data, clinical information from the ED, and data on neurosurgical interventions. Moreover, it includes the mechanisms of injury and time intervals (injury – ED admission – head CT – ED discharge). The destination after the ED was categorized into four groups: home, hospital ward, local health center, or death.

Health history was reviewed for pre-injury diseases which were grouped according to ICD-10 to the following groups (yes / no): (1) Certain infectious and parasitic diseases; (2) neoplasms; (3) diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism; (4) endocrine, nutritional and metabolic diseases; (5) mental and behavioral disorders; (6) diseases of the nervous system; (7) diseases of the eye and adnexa; (8) diseases of the ear and mastoid process; (9) diseases of the circulatory system; (10) diseases of the respiratory system; (11) diseases of the digestive system; (12) diseases of the skin and subcutaneous tissue; (13) diseases of the genitourinary system; (14) pregnancy, childbirth and the puerperium; (15) certain conditions originating in the perinatal period; and (16) Congenital malformations, deformations and chromosomal abnormalities.

Cervical CT imaging was performed with the same scanner as for the head CTs. CSI was defined as a fracture or subluxation of any of the cervical vertebrae. Whiplash injuries without radiological findings were not included in the analysis. The injured cervical spine level, including occipital condyle (C0) fracture, together with a detailed anatomic description of each vertebra and CT-detectable ligament injury, were recorded systematically. On clinical basis, MRI was performed on the spinal cord injured patients, but their results were not analyzed in this study.

4.4.4 Statistical methods

In Study I, the data were drawn from the entire population of Finland and therefore the numbers and incidences of cases are true descriptions of the entire Finnish population and not cohort-based estimates. The epidemiological data of the CSI patients were analyzed as a whole but also grouped according to age in patients under 60 years, and patients 60 or older. The frequencies and percentage of the analyzed variables were formed using descriptive statistics.

In Study II, III, and IV continuous variables were analyzed with the Pearson (normal distribution) and Spearman (skewed distribution) correlation coefficients. Group comparisons were tested with the Student’s t-test (normal distribution) and the Mann-Whitney U-test (skewed distribution). Statistical significance was set at $p<0.05$. In Study IV, in order to take the multiplicity of comparisons into account (possibility of type I error), the Bonferroni inequality correction was applied for testing the differences in pre-injury disease incidence between different groups. The corrected significance level was set at $p<0.0031$ (0.05/16).

Continuous variables are presented as the mean, standard deviation (SD), median, 95% confidence interval (CI) and range. The normality of the variable distributions was tested using the Kolmogorov-Smirnov and Shapiro-Wilk tests. IBM SPSS Statistics 20.0 (IBM Corp. Armonk, NY, USA) was used to perform the statistical analyses.

5 RESULTS

5.1 Incidence of fatal CSI in Finland (Study I)

A total of 2,041 death certificates reported CSI as immediate, intermediate, main, or related cause of death in Finland between 1987 and 2010. The majority of CSIs (65%, n=1,316) were diagnosed only after the death of the patient. The average population of Finland during the 24-year study period was 5,157,442 (range 4,938,602 - 5,375,276), and altogether 1,179,305 deaths were reported during that time (Official Statistics of Finland (OSF)). CSI contributed to approximately 0.2% of all deaths. The average annual incidence of fatal CSI was 16.5/million/year (range: 12.5–21.2) during the study period. A notable increase in the fatal CSI incidence began at the end of 1990s (Figure 4 and 5). During 2001-2010, the average annual number of fatal CSIs was 100, and the average incidence 19/million/year.

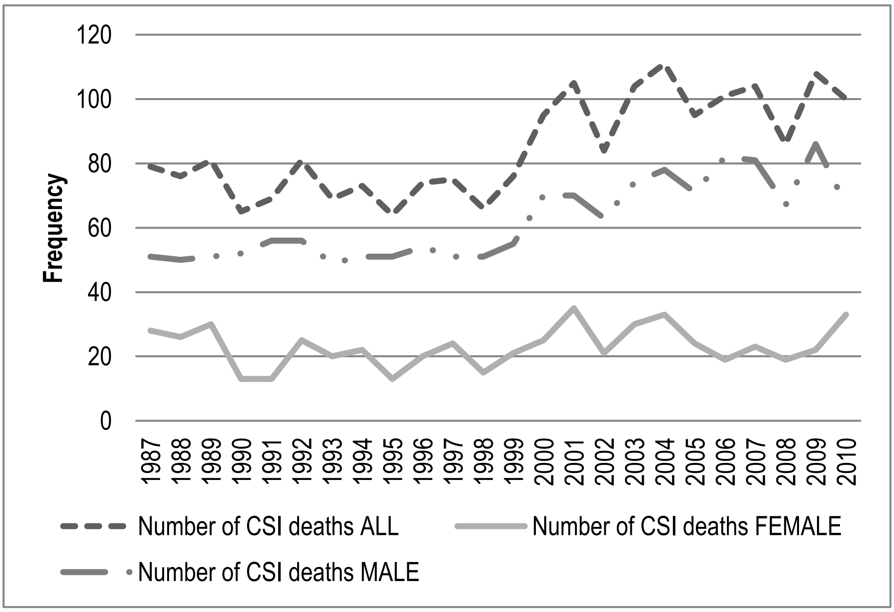


Figure 4. Number of CSI-related deaths per year in Finland between 1987 and 2010 (Study I, reprinted with permission).

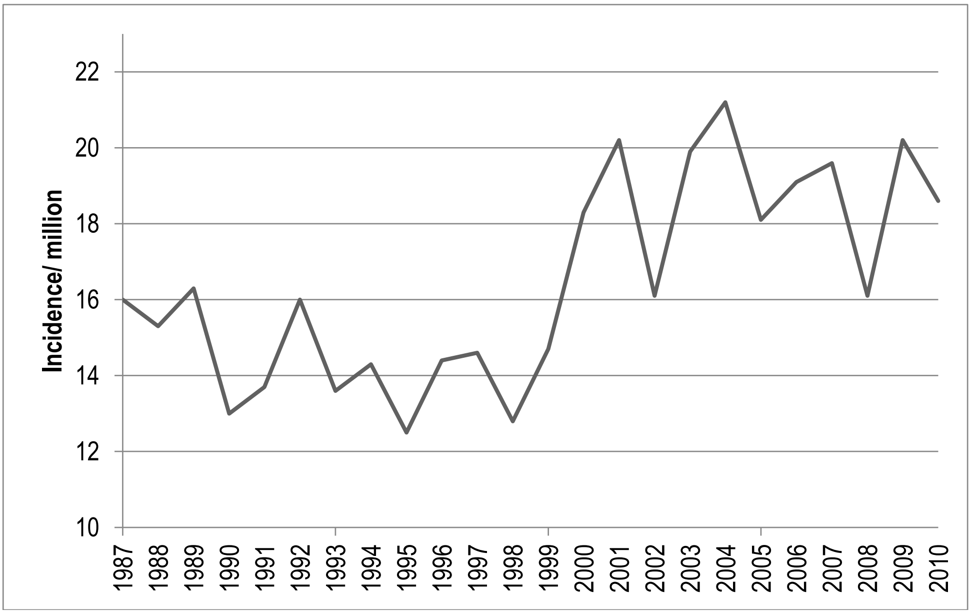


Figure 5. Incidence of CSI-related deaths per year in Finland between 1987 – 2010.

5.2 Patient - and injury characteristics of fatal CSI victims

Patient –and injury characteristics of the subjects in Studies I and II are presented in Table 2

Table 2. Patient and injury characteristics of the 2,041 fatally cervical spine injured victims in Finland over the 24-year study period from 1987 to 2010 (Study I, reprinted with permission).

	All	Under 60 years	60 years and older
Number of patients, n (%)	2,041	871 (42.7)	1,170 (57.3)
Gender, n (%)			
Female	554 (27.1)	218 (25)	336 (28.7)
Male	1,487 (72.9)	653 (75)	834 (71.3)
Age at death, mean ± SD (years)	59.4 ± 23	36.9 (15.5)	76.2 (9.1)
Female	61.4 ± 25.2	34.4 (16.8)	78.9 (9.2)
Male	58.7 ± 22.1	37.7 (15)	75.1 (8.9)
Alcohol mentioned, n (%)	608 (29.8)		
Female	82 (14.8)	53 (24.3)	29 (8.6)
Male	526 (35.4)	302 (46.2)	224 (26.9)
Drugs mentioned, n (%)			
Female	14 (2.5)	15 (2.5)	16 (2.5)
Male	49 (3.3)	38 (5.8)	11 (1.3)
Spinal cord injury, n (%)			
Female	441 (79.6)	207 (95.0)	234 (69.6)
Male	1,253 (84.3)	620 (94.9)	633 (75.9)
Cause of injury, n (%)			
Fall	919 (45)	143 (16.4)	776 (66.3)
Ice	14 (0.7)	2 (0.2)	12 (1.0)
Same level	415 (20.3)	25 (2.9)	390 (33.3)
From bed	28 (1.4)	0	28 (2.4)
Stairs	204 (10.0)	50 (5.7)	154 (13.2)
Ladder	13 (0.6)	2 (0.2)	11 (0.9)
Diving into water	11 (0.5)	10 (1.1)	1 (0.1)
>1 metre	96 (4.7)	35 (4.0)	61 (5.2)
Unspecified	138 (6.8)	19 (2.2)	119 (10.2)
Traffic	828 (40.1)	511 (58.7)	317 (27.1)
Pedestrian	106 (5.2)	59 (6.8)	47 (4.0)
Bicycle	110 (5.4)	52 (6.0)	58 (5.0)
Motorbike	65 (3.2)	49 (5.6)	16 (1.4)
Car	501 (24.5)	327 (37.5)	174 (14.9)
Off-road motor vehicle	7 (0.3)	5 (0.6)	2 (0.2)
Water transport	2 (0.1)	2 (0.2)	0
Aircraft	3 (0.1)	3 (0.3)	0
Unspecified	34 (1.7)	14 (1.6)	20 (1.7)
Assault	34 (1.7)	27 (3.1)	7 (0.6)
Firearm	15 (0.7)	14 (1.6)	1 (0.1)
Other	19 (0.9)	13 (1.5)	6 (0.5)
Event of undetermined intent (firearm)	3 (0.1)	3 (0.3)	0
Event of undetermined intent (other)	21 (1.0)	13 (1.5)	8 (0.7)
Suicide	178 (8.7)	156 (17.9)	22 (1.9)

Other traumatic	43 (2.1)	16 (1.8)	27 (2.3)
Unspecified	15 (0.7)	2 (0.2)	13 (1.1)
Cause of death, n (%)			
Disease	188 (9.2)	16 (1.8)	172 (14.7)
Occupational disease	2 (0.1)	0	2 (0.2)
Accident	1,605 (78.6)	649 (75.0)	956 (81.7)
Medical treatment	2 (0.1)	0	2 (0.2)
Suicide	178 (8.7)	156 (17.9)	22 (1.9)
Homicide	34 (1.7)	27 (3.1)	7 (0.6)
Unknown	32 (1.6)	23 (2.6)	9 (0.8)
Accident subclassification, n (%)			
Traffic	783 (48.8)	493 (76.0)	290 (30.3)
Occupation	32 (2.0)	23 (3.5)	9 (0.9)
Sport	9 (0.6)	6 (0.9)	3 (0.3)
Leisure	103 (10.8)	36 (5.5)	67 (7.0)
Home	417 (25.0)	40 (6.2)	377 (39.4)
Medical facility	58 (3.6)	3 (0.5)	55 (5.6)
Other	150 (9.3)	37 (5.7)	113 (11.8)
Unknown	47 (2.9)	10 (1.5)	37 (3.9)
Missing	6 (0.4)	1 (0.2)	5 (0.5)
Place of death, n (%)			
Medical facility	805 (39.4)	146 (16.8)	659 (56.3)
Home/residence	290 (14.2)	79 (9.1)	211 (18.0)
Other	921 (45.1)	628 (71.9)	295 (25.2)
Abroad	25 (1.2)	20 (2.3)	5 (0.4)
Cervical spine, injury level, n (%)			
C0–C2 injury	839 (41.1)	441 (50.6)	398 (34)
C3–C7 injury	1,202 (58.9)	430 (49.4)	772 (66)
Time since injury to death, mean ± SD (days)	46.7 ± 497	38.4 ± 553	54.6 ± 451
Time since injury to death, number of patients, n (%)			
<24 hours	1,291 (64.3)	741 (86)	550 (48)
1–7 days	248 (12.4)	41 (4.8)	207 (18.1)
8–30 days	212 (10.6)	37 (4.3)	175 (15.2)
31 days–1 year	226 (11.3	37 (4.3)	189 (16.5)
>1 year	30 (1.5)	6 (0.7)	24 (2.1)
Data missing	34 (1.7)		

5.2.1 Gender, age and alcohol

Of all of the 2,041 CSI victims, 72.9% were male and the overall male to female ratio was 2.6:1. The mean age at death was 59 years and 57% of the victims were over 60 years old. Ninety-one (4.5%) patients were adolescent or children (<18 years). There was a clear increase in the mean age at the time of death – from 54 to 68 years – during the study period (see Figure 6). Table 3 describes the share of CSI patients in each ten-year age group and their change in incidence between the first and last nine years of the study. The largest groups were patients aged 60-70 years (17%, n= 355) and 70-80 years (19%, n=395). Towards the end of the study, the share of older patients increased notably.

Alcohol was mentioned in 608 (29.8%) and non-prescription drugs in 63 (3.1%) of the death certificates. Among < 60 years old male victims, alcohol was present in 46.2% (302) of the cases. The share of alcohol intoxicated patients remained more or less the same during the whole study period.

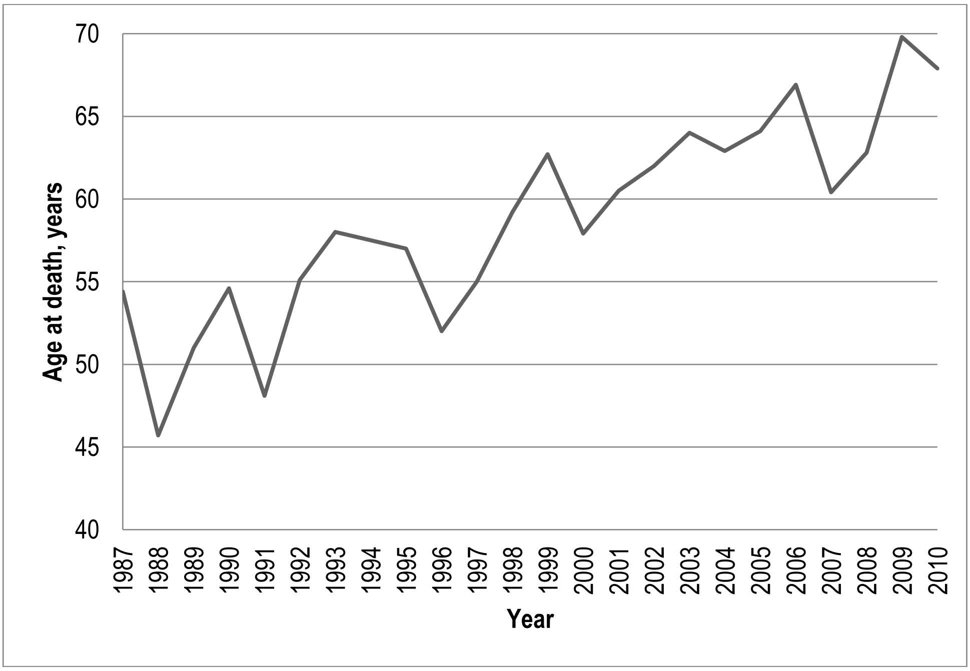


Figure 6. Mean age at death of fatally cervical spine injured patients in Finland between 1987 and 2010 (Study I, reprinted with permission).

Table 3. Total number of CSI cases per ten year age group, proportion of spinal cord injury victims, and comparison of the number of cases in years 1987–1995 and 2002–2010 (the first and last nine years of the study period) (Study I, reprinted with permission).

Age group (years)	Total number of CSI victims, n (%)	Proportion of spinal cord-injured victims, n (%)	Number of CSI victims between 1987–1995, n (%)	Number of CSI victims between 2002–2010, n (%)	Change between 1987–1995 and 2002–2010 n (%)
0–9.9	41 (2.0)	40 (97.6)	26 (4.0)	5 (0.6)	-21 (-80.8)
10–19.9	100 (4.9)	99 (99)	47 (7.2)	25 (2.8)	-22 (-46.8)
20–29.9	183 (9.0)	178 (97.3)	75 (11.4)	70 (7.8)	-5 (-6.7)
30–39.9	142 (7.0)	141 (99.3)	67 (10.2)	41 (4.6)	-26 (-38.8)
40–49.9	170 (8.3)	155 (91.2)	57 (8.7)	66 (7.4)	9 (+15.8)
50–59.9	235 (11.5)	214 (91.2)	65 (9.9)	98 (11.0)	33 (+50.8)
60–69.9	355 (17.4)	299 (84.2)	118 (18.0)	152 (17.0)	34 (+28.8)
70–79.9	395 (19.4)	313 (79.2)	115 (17.5)	187 (20.9)	72 (+62.6)
80–89.9	338 (16.6)	217 (62.2)	81 (12.3)	188 (21.1)	107 (+132.1)
90–99.9	82 (4.0)	38 (46.3)	6 (0.9)	61 (6.8)	55 (+916.7)
Total	**2,041 (100)**	**1,694 (83.0)**	**657 (100)**	**893 (100)**	**236(+35.9)**

5.2.2 Injury mechanism and place of death

The most common injury mechanisms were falls (n=919, 45%) and traffic accidents (n=828, n=40%). The mechanism of injury varied significantly by age. Young and middle-aged victims (<60 years) were often injured in fatal traffic accidents (n=511, 59%) or in suicides (n=156, 18%). Older (≥60 years) victims were injured most often in falls (n=776, 66%) which were mostly regarded as low-energy injuries. There were only nine sports related injuries and 11 injuries resulting from diving into water (Table 2).

There were significant differences in the place of death for different age groups. Of the older victims, 56% (n=659) died in a medical facility and 18%

(n=211) at their home/residence, while for younger victims, the place of death was generally (72%) the scene of an accident outside one's home (coded as "other" in death certificates) (Table 2).

The number of fall-related CSIs exceeded traffic accident-related CSIs in 1999 (Figure 7). The increase in the total number of CSI victims is explained for the most part by the increase in fall-related accidents of elderly males, which is shown in Figure 8. Nevertheless, traffic accident-related fatal CSIs still occur, and towards the end of the study period the age of the traffic accident patients increased. The greatest decrease in traffic-related fatal CSI incidence was among pedestrians. The trend in car accident-related fatal CSI decreased only marginally and for the most part among patients under 60 years of age (Figure 9). The number of pediatric patients decreased towards the end of the study period (Table 2).

Figure 7. Number of fall-related and traffic accident related fatal CSI injuries per year in Finland between 1987 and 2010.

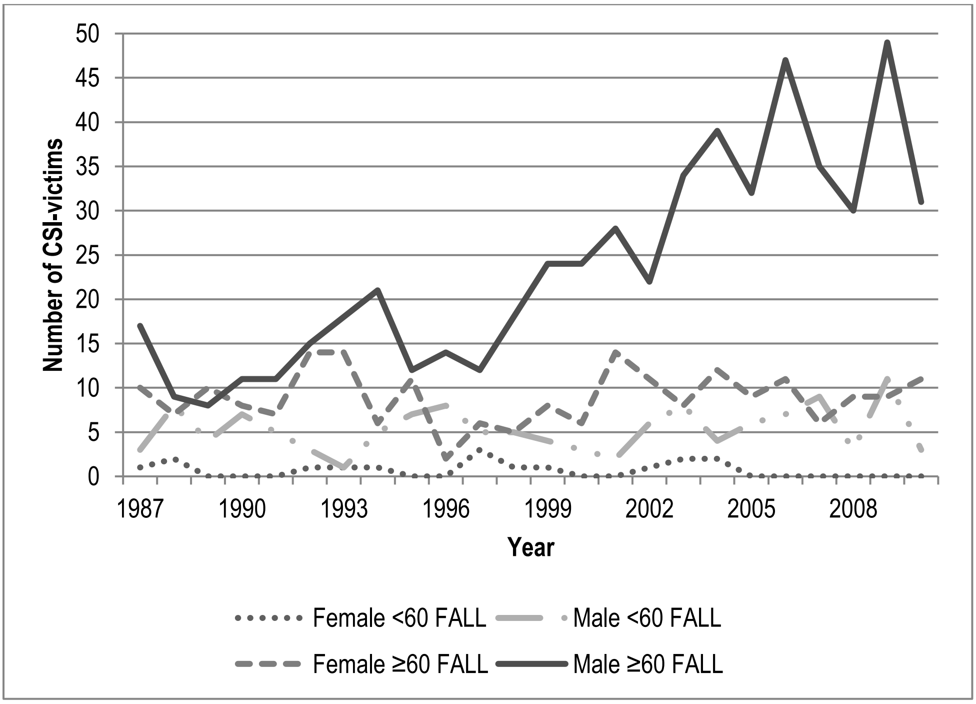


Figure 8. Number of cervical spine injury (CSI) - related deaths caused by fall-induced accidents per year in < 60 and ≥ 60-year-old patients (Study I, reprinted with permission).

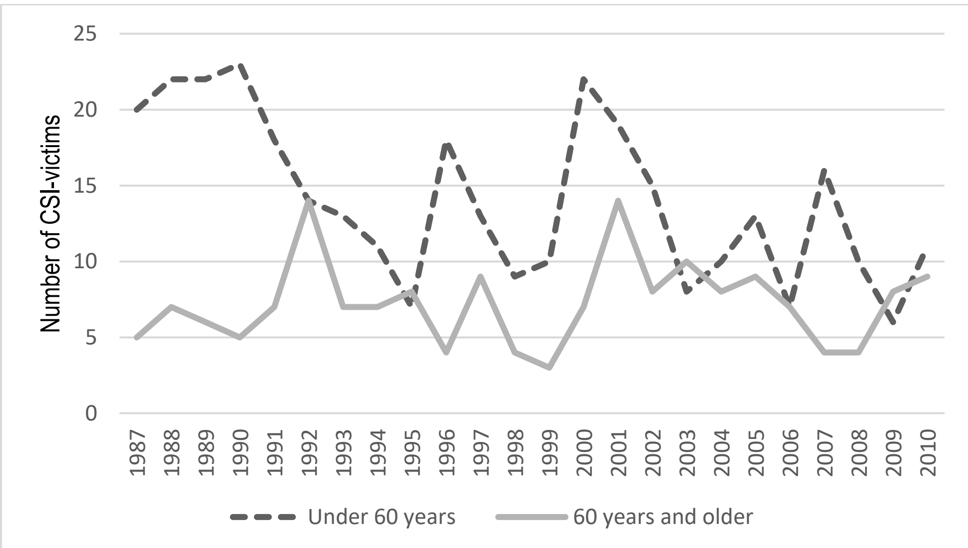


Figure 9. Number of cervical spine injury (CSI) – related deaths by car accident per year in < 60 and ≥ 60-year-old patients in Finland between 1987 and 2010.

5.2.3 Day and month of injury and Interval between injury and death

The most common day of CSI was Saturday (18%, n=368). As shown in Figure 10, younger patients (<60 years) especially tended to get injured towards the end of the week (Friday and Saturday, 39%). For elderly patients, there were no big variations regarding the day of injury. Regarding the month of injury, there was some preponderance in the summer months in the CSI frequency. The most frequent month of injury was July (10%, n=206) (Figure 11).

The mean time between injury and death was 46.7 days (median: 0 days, min 0, and max 37.9 years). There were considerable variations in time intervals between young (<60 years) and old (≥ 60 years) patients. Younger patients died during the day of injury in the majority of cases (86%, n=741), whereas older patients did so in less than half of the time (48%, n=550). A substantial number (33.2%, n=388) of older patients lived more than one week post-injury (Table 2). To summarize, young patients mainly died immediately due to high-energy traffic accidents and old patients due to the sequalae of falling accidents.

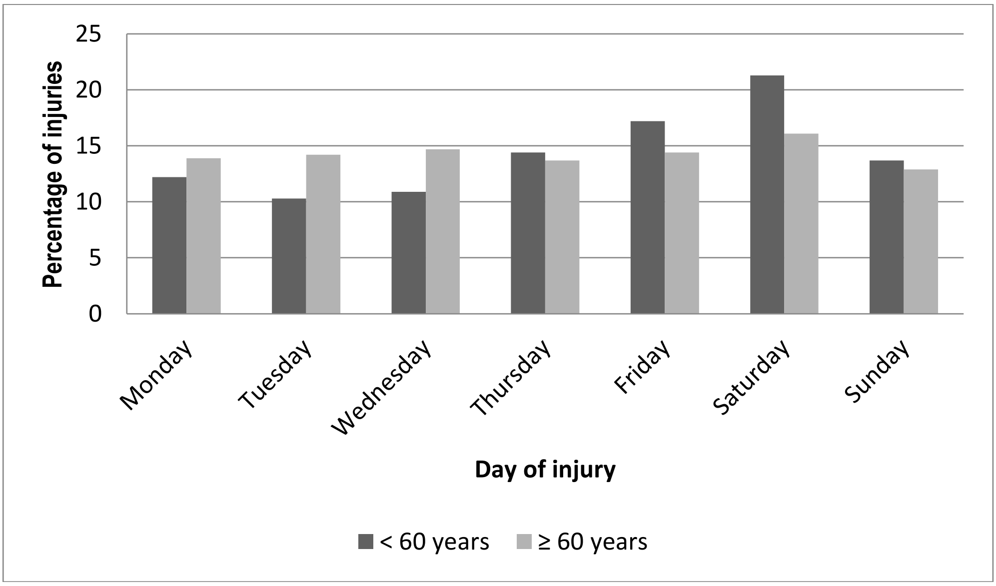


Figure 10. Day of injury in < 60 - and ≥ 60-year-old fatally cervical spine injured patients in Finland between 1987 and 2010.

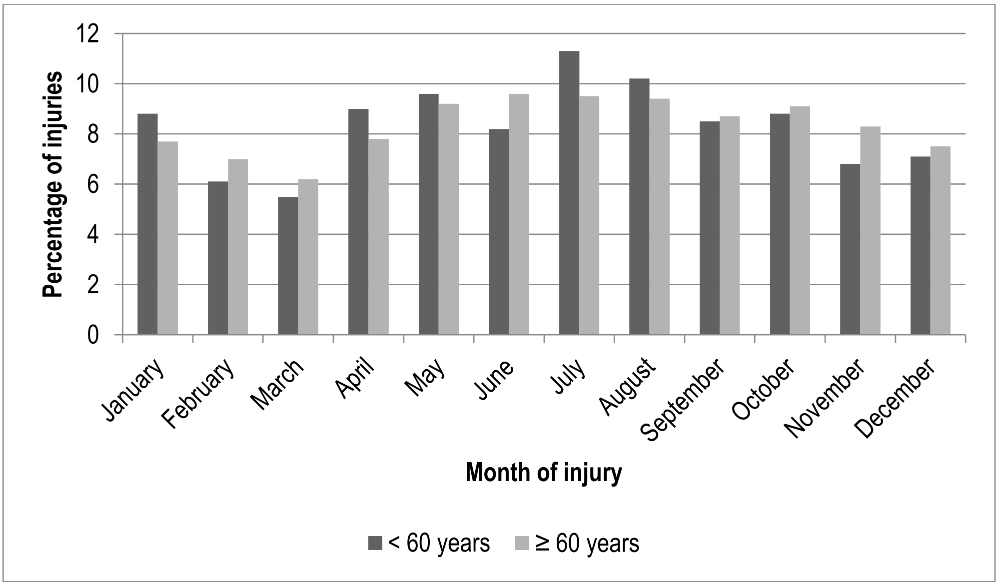


Figure 11. Month of injury in < 60 - and ≥ 60-year-old fatally cervical spine injured patients in Finland between 1987 and 2010.

5.2.4 Causes of death

CSI was the main cause of death in 90.5% (n=1,847) and related cause of death in 9.5% (n=193) of the fatally cervical spine injured patients. Among those who died during the day of injury (n=1,297) (most often at the scene of the accident), CSI was the main cause of death 95.8% (1,243) of the time. Among elderly patients (≥60 years, n=1170) the main cause of death was relatively often (n=179, 15.3%) other than a CSI. Among elderly patients, who died more than one week after the CSI, the immediate causes of death were mostly respiratory (n=234, 60%) or circulatory (n=54, 13.9%) diseases.

5.2.5 Level of injury

CSI occurred most often in the C3-C7 region (58.9%, n=1,202), (including combined upper and lower injuries as well as miscellaneous injuries). Young patients (<60 years) had an upper CSI (C0-C2) in about half of the cases (51%, n=441). Of those, SCI was present 96.1% (n=424) of the time and the majority (91.8, n=402) of these patients died during the day of injury (mostly immediately at the scene of the accident). However, in the older patient group (≥ 60 years), 34.0% (n=398) had an upper CSI and only 65.3% (n=260) of them had a SCI. Only about half (49.6%, n=194) of the older patients with upper injury died during the day of injury.

5.2.6 Incidence and share of spinal cord injury in relation to patient´s age

Spinal cord injury was found in 1,694 (83.0%) cases and in 91.2% (n=1,177) of the patients who died during the day of injury. The incidence of spinal cord injury decreased with increasing age so that in the oldest age group (90-100 years) less than half (46.3%) had an SCI whereas among patients less than 40 years, almost all (98%) had an SCI (Table 3).

5.2.7 Method of death certification (Study I and II)

In the study, a medicolegal autopsy was performed for 1,907 (93.4%) patients and clinical autopsy for 5 (0.2%) patients. In 121 (5.9%) cases, the death certificate was written by the treating physician without an autopsy, and in eight (0.4%) cases the type of death certification was unknown. Among those who died during the day of injury, medicolegal autopsy was performed in 1,291 (99.5%) cases, and among those who died later than the day of injury in 616 cases (82.8%).

5.3 Preventable adverse events (Study II)

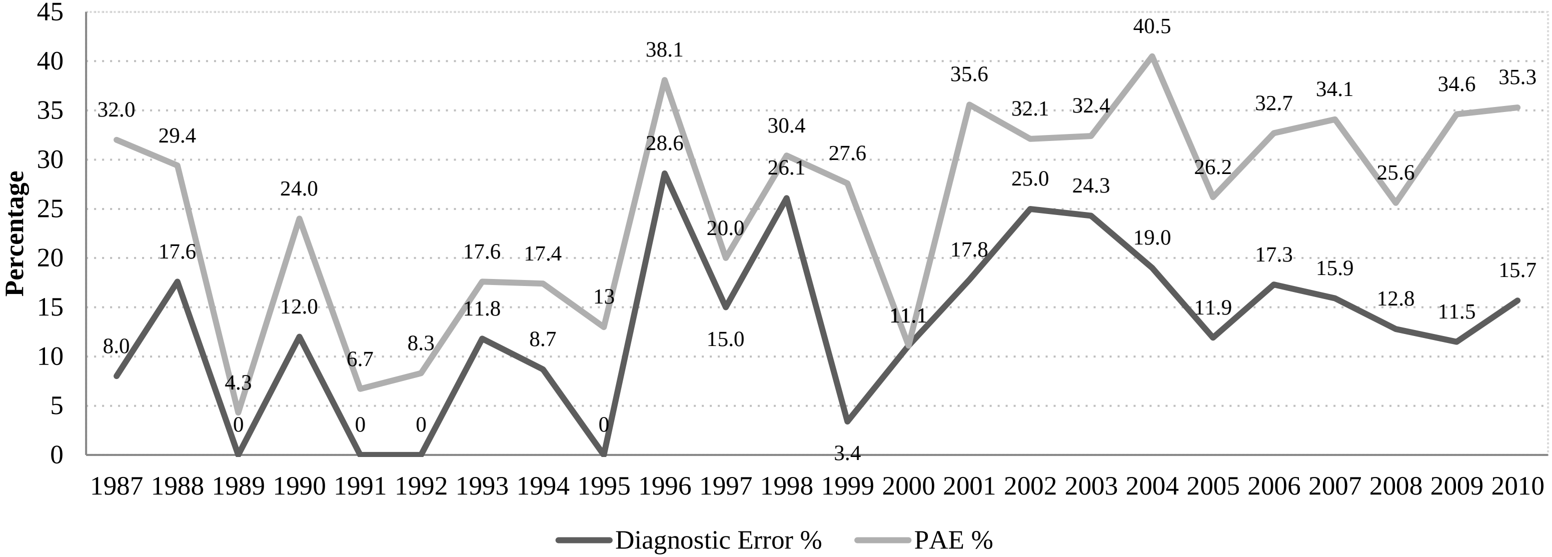
5.3.1 Comparison between patients who died during the day of injury and patients who survived longer than the day of injury (Study II)

Out of the 2,041 CSI-related deaths, 36.5% (n = 744) happened later than the date of injury. The patients who survived at least until the next day were significantly older (76 years vs. 55 years, $p<0.001$), the injury mechanism was more often a fall (72%, n = 536 vs. 30%, n = 383, $p<0.001$), and the place of death was more often a medical facility (94%, n = 698 vs. 8%, n = 107, $p<0.001$). Alcohol consumption (37%, n = 482 vs. 17%, n = 126, $p<0.001$), the incidence of spinal cord injury (91%, n = 1,182 vs. 69%, n = 512, $p<0.001$), and the rate of upper

CSIs (46%, n = 598 vs. 32%, n = 241, p<0.001) were higher among those who died on the day of injury.

5.3.2 Incidence of preventable adverse events

Of those CSI patients who survived at least until the next day, a PAE was identified in 27.7% (n = 206), of which half (n = 103) were considered diagnostic errors. In 5% (n = 37) of those who survived at least until the next day, a PAE could not be determined as being present or not. The number of PAEs and diagnostic errors increased during the study period, but so did the number of all CSI patients. The ratio of PAEs or diagnostic errors in relation to the number of all CSI patients increased slightly during the study years (Figure 12). The PAEs (n = 206) were classified into six different categories: diagnostic errors, health care facility-related events, treatment-related events, secondary complications, surgical treatment-related events and other events (Table 4). The most frequent recorded PAE types were related to CSI diagnostics and health care facility-related events.



Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Diagnostic error (n)	2	3	0	3	0	0	2	2	0	6	3	6	1	3	8	7	9	8	5	9	7	5	6	8
PAE (n)	8	5	1	6	1	2	3	4	3	8	4	7	8	3	16	9	12	17	11	17	15	10	18	18
All patients (n)	25	17	23	25	15	24	17	23	23	21	20	23	29	27	45	28	37	42	42	52	44	39	52	51

Figure 12. The annual percentages of patients with preventable adverse events (PAE) and diagnostic errors for all patients with CSIs who died after the day of injury (n = 744) (Study II, reprinted with permission).

Table 4. Preventable adverse events (n = 206) in fatal CSI patients who died after the date of injury stratified into six categories (Study II, reprinted with permission).

Preventable adverse event category	N	%
Total	206	100.0
Diagnostic errors	103	50.0
CSI diagnosis missed during lifetime	59	28.6
CSI diagnosis delayed	41	20.0
Diagnostic other	3	1.5
Health care facility related events (fall at the ward, fall from bed, wrong place of treatment, or fell from wheelchair)	36	17.5
Treatment related events (wrong treatment, CSI operation not performed, supine skull traction for elderly, medication related, related to halo for stabilizing head and neck, iatrogenic aspiration of blood, too early extubation, or post-operative bleeding related to anticoagulant treatment)	31	15.0
Secondary complications (pressure ulcer, pulmonary embolism, or preventable aspiration)	20	9.7
Surgical treatment related events (peri-operative death, surgical hardware error, suboptimal operation, or post-operative infection/hematoma)	12	5.8
Other (post-surgery brain infarction, removal of collar by patient, or NORO-diarrhea)	3	1.5

5.3.3 Characteristics of patients with preventable diagnostic error

Patient characteristics, injury-related information, and diagnostic error data are presented in Table 5. Diagnostic error occurred most of the time in specialized health care (55%). Patients with diagnostic errors were significantly older (79.4 vs. 74.9 years, $p = 0.001$), and the injury mechanism was significantly more often a fall compared to CSI patients who did not have a diagnostic error. Median time from injury to death was significantly shorter in the diagnostic error group (seven days compared to 17 days, $p < 0.001$). Examples of typical cases with a diagnostic error are presented in Table 6. One of the most typical diagnostic errors was the lack of suspicion of a CSI (Table 6, examples 1 and 4).

Table 5. Characteristics of patients with CSIs who died after the day of injury stratified by whether or not the patients experienced a diagnostic error (Study II, reprinted with permission).

	Diagnostic error n=103		No diagnostic error n=641			Total n=744	
	n	%	n	%	p	n	%
Gender					0.873		
Female	24	23.3	154	24		178	23.9
Male	79	76.7	487	76		566	76.1
Age at death, years, median (95% CI)	79.4 (75.9-80.1)		74.9 (70.2-72.9)		0.001	75.7 (71.3-73.6)	
Alcohol mentioned	20	19.4	106	16.5	0.469	126	16.9
Drugs mentioned	0	0	4	0.6	0.421	4	0.5
CSI as main cause of death	79	76.7	525	81.9	0.21	604	81.2
C0-C2 injury	28	27.2	213	33.2	0.224	241	32.4
Spinal cord injury	66	64.1	446	69.6	0.263	512	68.8
Cause of injury					0.002		
Fall	89	86.4	447	69.7		536	72
Traffic accident	8	7.8	150	23.4		158	21.2
Suicide	0	0	5	0.8		5	0.7
Other traumatic or unspecified	6	5.8	39	6.1		45	6
Place of death					0.647		
Medical facility	95	92.2	603	94.1		698	93.8
Home or residence	6	5.8	23	3.6		29	3.9
Other	2	1.9	12	1.9		14	1.9
Abroad	0	0	3	0.5		3	0.4
Time since injury to death, Median, Days (min-max)	7 (1-1,442)		17 (1-13,849)		<0.001	16 (1-13,849)	
Time since injury to death					0.005		
1-7 days	49	47.6	198	30.9		247	33.2

8-30 days	27	26.2	183	28.5		210	28.2
31 days-1 year	19	18.4	206	32.1		225	30.2
> year	2	1.9	28	4.4		30	4.0
Data missing	6	5.8	26	4.1		32	4.3
Death certification					0.023		
No autopsy	7	6.8	113	17.6		120	16.1
Hospital autopsy	0	0	5	0.8		5	0.7
Medicolegal autopsy	95	92.2	521	81.3		616	82.8
Other	1	1	2	0.3		3	0.4
Place of diagnostic error							
Primary health care	41	39.8	-	-		41	5.5
Spezialized health care	57	55.3	-	-		57	7.7
Undetermined	5	4.9	-	-		5	0.7

Table 6. Examples of typical cases with preventable diagnostic errors. (Modified from Study II, reprinted with permission).

1	79-year-old male with a history of Parkinson's disease, coronary artery disease with a prior heart infarct and periodic heart arrhythmia. Moving with aid of a walker. Frequent ground level falls. He was brought to a central hospital because of a ground level fall and subsequent difficulties with getting up and moving. Traumatic intracranial changes were not detected. He was hospitalized and he died nine days later. According to the medicolegal autopsy, the main cause of death was a fracture of the C5 vertebra and medullary contusion. The immediate cause of death was pneumonia. Contributing causes of death were Parkinson's disease and coronary artery disease. Diagnostic error: lack of suspicion of a CSI.
2	80-year-old male. No information about chronic diseases. He fell from a rocking chair and hyperflexed his neck. Primarily neck roentgenogram and neck CT were considered negative. After two weeks he developed tetraparesis and C5/C6 listhesis was detected. An anterior decompression and fixation procedure were performed. After operation, excessive mucous secretion. He died during the insertion of a feeding tube 29 days after injury. According to the medicolegal autopsy the main cause of death was a C5/C6 level luxation with tetraplegia. Immediate cause of death was pneumonia. Diagnostic error: Image misinterpretation or inadequate imaging.
3	82-year-old male with coronary artery disease. Heart insufficiency, hypertension, chronic obstructive pulmonary disease and diabetes. In 2004, he fell from bed at home. On the next day, he was taken in to a health care center ward due to pain in the shoulder and chest.

	Heart infarct was not diagnosed. Afterwards pain localized more to the neck and due to unclear symptoms he was referred to a central hospital five days later. He was tired and had shortness of breath and excess mucous secretion was observed. Cervical spine roentgenogram and head CT were negative. He was found dead in a hospital ward bed eight days after the fall. According to the medicolegal autopsy the main cause of death was fracture of the C6 with a medullary lesion. Intermediate cause of death was bronchopneumonia incipiens. Immediate cause of death was bronchial aspiration. Contributing causes of death were fulminant coronary artery disease and pulmonary emphysema. Diagnostic error: inadequate imaging.
4	90-year-old male. No information about chronic diseases. Walking frame assisted moving. In 1998, he fell at home. He was transferred to a local health care center where he complained of pain in his left shoulder. He was taken in to the healthcare center ward where increasing spasticity was observed in the left shoulder area. He was transferred to a central hospital 17 days after the injury where a cervical spine fracture was detected and an external fixation device was inserted. He was transferred back to the health care center where he died 36 days after injury. According to the medicolegal autopsy, the main and immediate causes of death was a C7 fracture with a medullary contusion. Diagnostic error: lack of suspicion of a CSI and delayed imaging.

5.4 Concurrence of head injury and cervical spine fracture (Study III and IV)

Of the whole cranio-cervically CT-imaged group of patients (n=1,091), 65.4% (n=714) were male. Falls (47.8%, n=521) and car accidents (22.4%, n=244) were the most frequent injury mechanisms. Of all the patients (n=1,091), 607 (55.6%) fulfilled the clinical criteria for mild TBI, 201 (18.4%) had a moderate or severe TBI and the rest (n=283, 25.9%) had a head trauma without clear signs of TBI. Cervical spinal cord injury was found in 13 (16.9%) of the CSI patients. In one patient, the existence of a possible spinal cord injury remained unknown due to early death caused by a severe TBI.

5.4.1 Cervical spine fractures in patients with CT-positive versus CT-negative head injuries

Patients who had acute traumatic intracranial lesions in head CT (9.3%, n=25) had significantly more cervical spine fractures (Pearson chi-square, p=0.04; OR=1.689, 95% CI=1.019-2.802) compared to those who did not have intracranial lesions visible in head CT (5.7%, n=47). However, patients with positive head CT scans had fewer spinal cord injuries (0.4%, n=1 versus 1.5%, n=12). Moreover, positive head CT findings had a significant association with C6 vertebra fractures (3.0%, n=8 versus 1.1%, n=9; p=0.031, OR=2.769, 95% CI=1.057-7.250), but not with other cervical vertebra fractures (C0-5 and C7) or dislocations/subluxations alone. Patients with positive head CT scans (2.2%, n=6) did not have more neurosurgical operations within one year post-HI due to cervical spine fractures compared with patients with negative head CT scans (3.2%, n=26; p=0.431). Comparisons between head CT-positive and head CT-negative patients are presented in Table 7.

Table 7. The CSI - characteristics of the study sample stratified into subgroups (head CT-positive patients, head CT-negative patients, and whole sample).

Variable	Head CT-positive patients (n=269)	%	Head CT-negative patients (n=822)	%	p-value	Whole sample (n = 1091)	%
Cervical spine surgery within one year post injury	6	2.2	26	3.2	0.431	32	2.9
Cervical spine fracture	25	9.3	47	5.7	0.04	72	6.6
Cervical dislocation / subluxation	8	3.0	23	2.8	0.880	31	2.8
Number of fractured cervical vertebrae	35	13.0	66	8.0	0.014	101	9.3
C0	2	0.7	2	0.2	0.431	4	0.4
C1	5	1.9	5	0.6	0.062	10	0.9
C2 (odontoid)	5	1.9	8	1.0	0.245	13	1.2
C2 (non-odontoid)	5	1.9	11	1.3	0.538	16	1.5
C3	2	0.7	4	0.5	0.621	6	0.5
C4	1	0.4	8	1.0	0.344	9	0.8
C5	4	1.5	8	1.0	0.483	12	1.1
C6	8	3.0	9	1.1	0.031	17	1.6
C7	5	1.9	15	1.8	0.971	20	1.8
Multilevel cervical spine fracture (> 1 levels)	9	3.3	13	1.6	0.074	22	2.0
Patients with lower level cervical fracture (C3-C7)	16	5.9	31	3.8	0.127	47	4.3
Patients with upper level cervical fracture (C0-C2)	11	4.1	19	2.3	0.122	30	2.7
Spinal cord injury	1	0.4	12	1.5		13	1.2
ASIA-scale					0.490		
A	1	0.4	2	0.2		3	0.3
B	0	0	4	0.5		4	0.4
C	0	0	5	0.6		5	0.5
D	0	0	1	0.1		1	0.1
E or unknown	268	99.6	810	98.5		1078	98.8

5.4.2 Cervical spine CT findings

On cervical CT, CSI was found in 7.1% (n=77) and cervical spine fracture in 6.6% (n=72) of the patients with HI (n=1,091). In total, these patients sustained 101 fractured vertebrae. Five patients had only a ligament injury without a fracture in CT imaging. Of the patients with CSI, 31 (40.3%) had dislocations and/or subluxations. Of the patients with fractures, 27 (37.5%) had dislocations and/or subluxations. The median dislocation between cervical vertebrae was three millimeters (range 1 - 10mm). The distribution of fractured vertebrae (n=101) is presented in Figure 13. The distribution of dislocations/subluxations is presented in Figure 14. Dislocations/subluxations occurred most often in the atlanto-axial (n=9) and C4/C5 (n=7) levels. The distribution of different fracture locations (n=161) within individual vertebrae in the upper cervical spine is presented in Figures 15, 16 and 17) and in the lower cervical spine in Table 8. In the atlas (C1), the fracture type was most often comminuted. In the axis (C2), odontoid process types 2 and 3 and lateral mass/articular process fractures prevailed. In the subaxial cervical spine, fractures involved most often the lateral masses/articular processes.

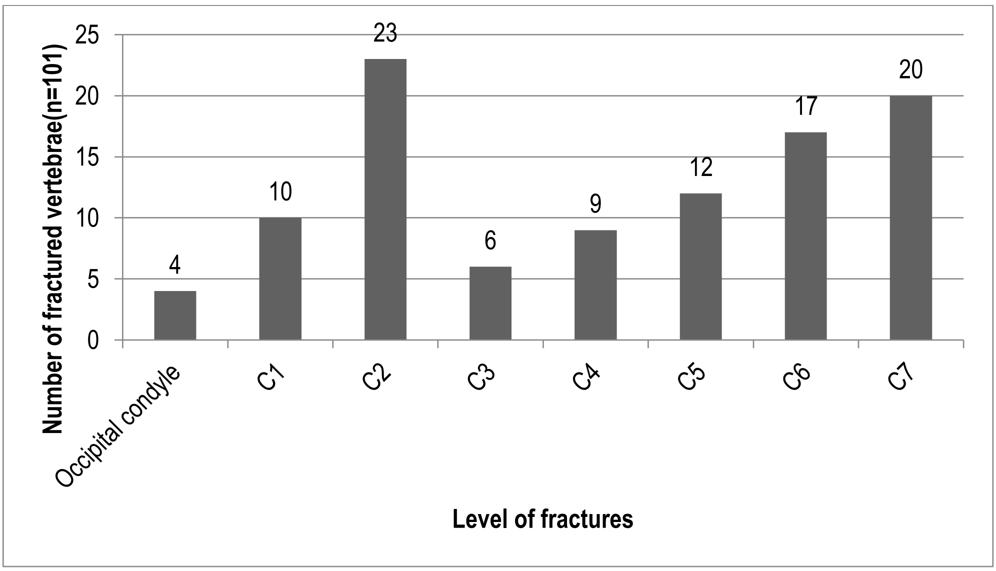


Figure 13. Level of cervical spine fractures (Study III, reprinted with permission).

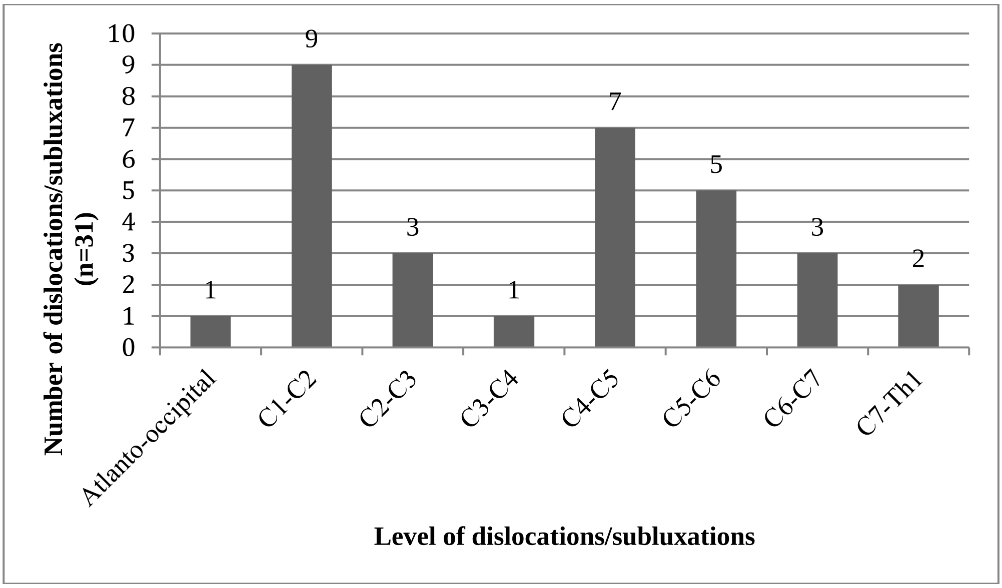


Figure 14. Level of dislocations/subluxations (Study III, reprinted with permission)

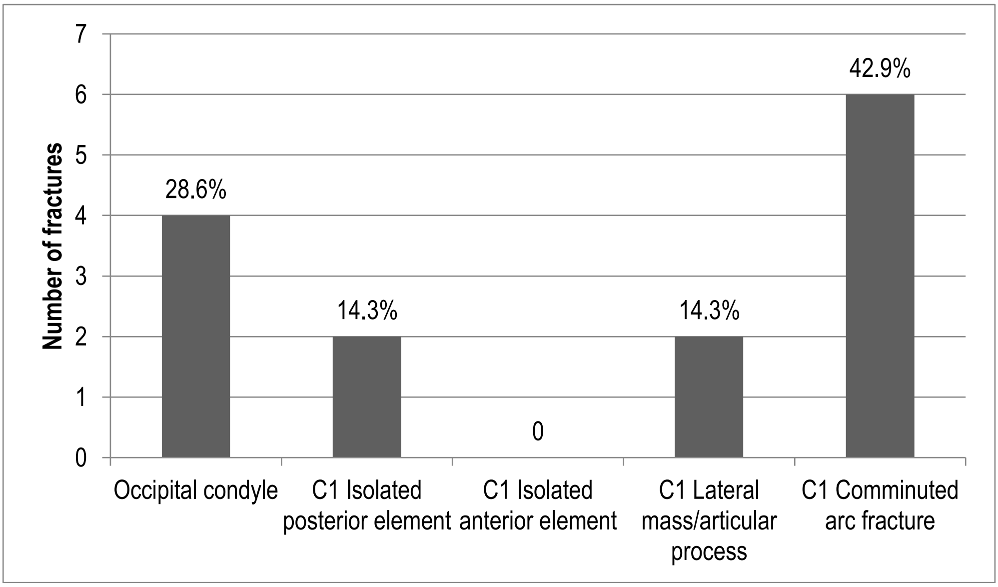


Figure 15. Location of fractures to C0-C1 vertebrae (Study IV).

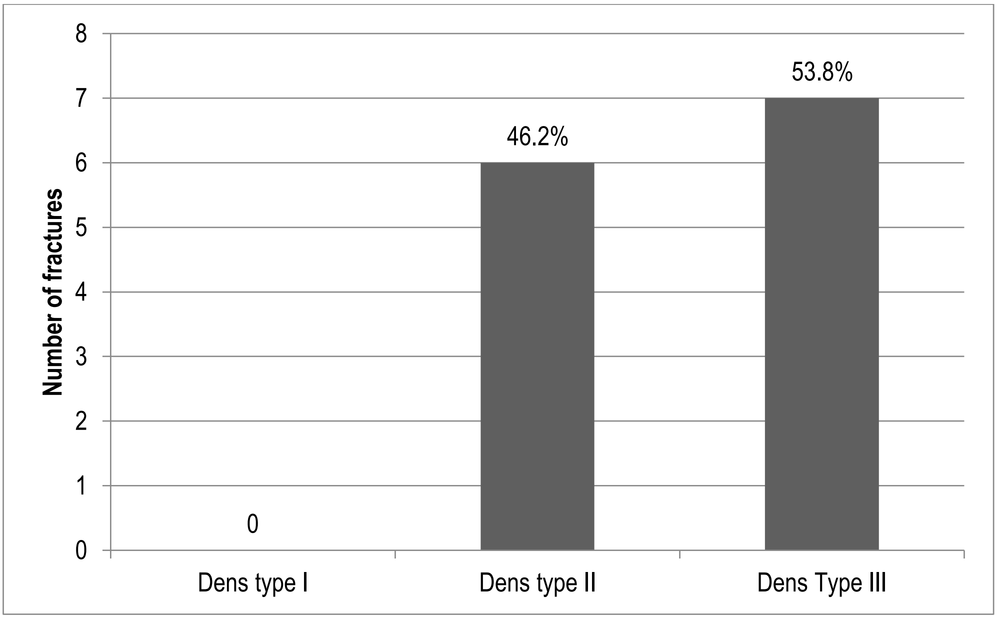


Figure 16. Distribution of C2 odontoid process fractures (n=13) (Study IV).

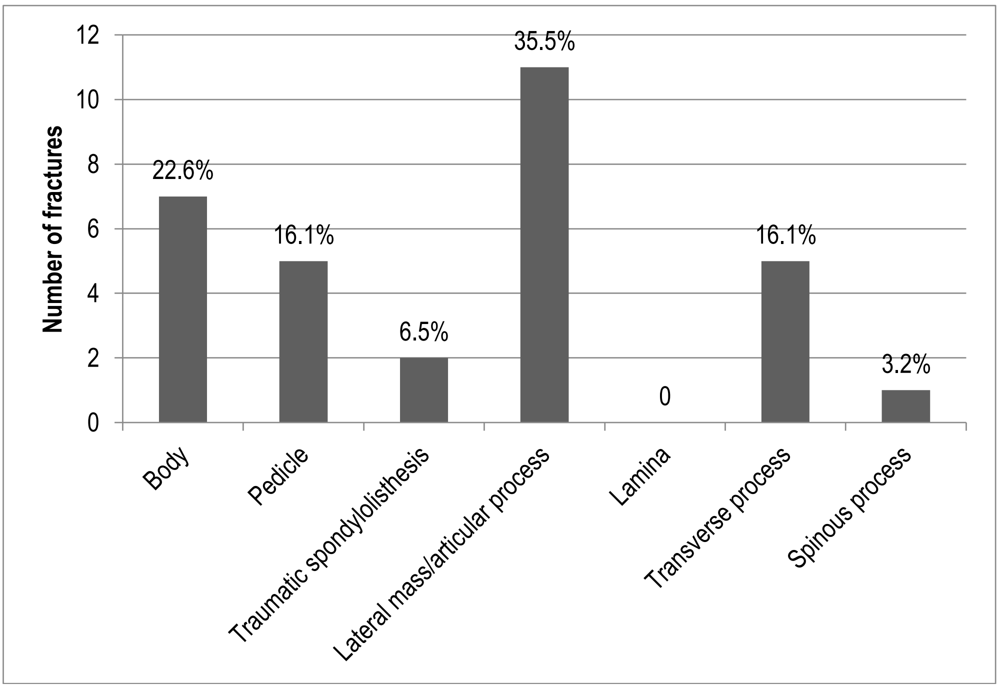


Figure 17. Distribution of non-odontoid fractures to the C2 vertebra (n=31) (Study IV).

Table 8. The distribution of subaxial fracture locations (Study IV).

Location	C3	C4	C5	C6	C7	Total	%
Body	3	4	4	4	3	18	17.5
Pedicle	-	3	2	-	3	8	7.8
Lateral mass/ articular process	1	7	8	5	12	33	32.0
Lamina	1	6	4	4	3	18	17.5
Transverse process	1	3	2	2	6	14	13.6
Spinous process	-	1	2	4	3	10	9.7
Other	1	-	-	1	-	2	1.9
Total	7	24	22	20	30	103	100.0

5.5 Risk factors for cervical spine fractures in head-injured patients (Study IV)

High age was a risk factor of cervical spine fractures among HI patients. Patients who had a cervical spine fracture were almost ten years older than patients who did not have a cervical spine fracture (median 55.5 versus 46.7 years, p=0.027). In addition, facial bone fractures (13.9%, n=10 versus 6.9%, n=70, p=0.027) and epidural hematomas (4.2%, n=3 versus 1.2%, n=12, p=0.035) were significantly more common in the fracture group and therefore may be considered as risk factors for cervical spine fractures. However, the total number of epidural hematomas was low to allow solid conclusions to be formulated. In addition, patients with a high-energy injury mechanism had more cervical spine fractures compared to patients with a low-energy injury (59.7%, n=43 versus 40.3%, n=29, p=0.021). Surprisingly, there were no statistical differences in the gender distribution, clinical TBI severity, GCS level or presence of alcohol intoxication between patients with or without a spine fracture. Patients with a cervical spine fracture were hospitalized longer (96.4 hours versus 21.3 hours, p<0.001) and more neurosurgical procedures (19.4%, n=37 versus 7.9%, n=81, p<0.001) were performed on them.

5.5.1 Primary diseases and the risk of cervical spine fractures (Study IV)

Only congenital malformations, deformations and chromosomal abnormalities were statistically more frequent in the fracture group (2.8%, n=2, versus 0.3%, n=3, p=0.003), but the total number was too low for solid conclusions to be made. Due to multiple family-wise comparison (possibility of type I error), Bonferroni correction was applied. The corrected significance level was set at <0.0031 (0.05/16). Diseases of the circulatory system (41.7%, n=30 versus 28.9%, n=294, p=0.021) had a tendency of being more frequent in the fracture group, which may reflect the higher age of these patients. Mental and behavioral diseases were common findings in the whole sample 25.6% (n=279), with no significant difference between the cervical spine fractured and non-cervical spine fractured patients.

6 DISCUSSION

6.1 Increasing trend in CSI incidence and change in patient profile

To the best of my knowledge, this is the first whole nation-wide study to report the incidence of fatal CSI. The epidemiological data published by most authors is based on hospitalized patients and therefore underestimates the incidence of certain injuries when leaving out casualties that died at the scene of an accident or patients who are erroneously diagnosed. We found that the majority (65%) of all fatal CSIs were diagnosed after the death of the patient. The death certificate-based incidence of CSI increased from 16/million/year to 19/million/year between 1987 and 2010. The most notable increase in the incidence has been after the year 1999, which is mainly explained by the increase in ground-level falls among elderly males (Figures 4, 5 and 8). This finding corroborates previous studies. The age of those deceased changed notably during the observation period (Figure 6). The mean age at the time of death increased from 54 years to 67 years, and the number of pediatric patients decreased significantly. This is probably partly due to improved road and in-car safety, and also the general safety precautions related to children’s living environment (i.e., school, home, hobbies etc.). Falls exceeded traffic accidents as the most common cause of CSI in 1998. The number of fall-induced accidents among elderly individuals started to increase at the end of the 1990s. It has been shown previously that even though in general, falling accidents are more frequent in the female population, most of the fall-induced severe CSIs happen to males (Kannus, Palvanen et al. 2007, Kannus, Parkkari et al. 2005). The reason for this phenomenon is unknown. It has been proposed that men are at greater risk of severe falls than women (Kannus, Palvanen et al. 2007). Moreover, ankylosing spinal disorders (AS and DISH), which increase the risk of cervical spine fractures, are more common in males. Fall prevention measures for the elderly are crucial since it is estimated that in Finland the number of people aged 65 or older is going to rise from the present

19.9% to 26% by the year 2030 (Official Statistics of Finland 2015 c). This puts 1.5 million Finnish seniors above the age of 65 years at risk of CSI with the current safety measures.

Traffic accidents continue to cause fatal CSI especially among men despite the decreasing general trend in all traffic accident-related fatal CSIs. Towards the end of the study, older patients especially contributed most to the number of traffic accident-related fatal CSIs. It has been shown previously that seatbelts and airbags reduce mortality after motor vehicle accidents, (Cummings, McKnight et al. 2002) and protect the cervical spine (Claytor, MacLennan et al. 2004). The use of seatbelts and airbags increased in Finland during the study years, but this did not influence much the incidence of fatal CSIs (Figure 5). In Finland, general road traffic mortality decreased from 581 per year to 272 per year between 1987 and 2010 (Official Statistics of Finland (OSF)). During the same time, fatal CSIs induced by traffic accidents decreased only marginally (Figure 7). In 1987, there were 1.9 million registered vehicles whereas in 2010 this had increased to 3.4 million. The strongest decline in traffic accident-related fatal CSIs was among pedestrians. Previously, Lieutaud et al. studied traffic-related SCIs in France between two observation periods (1996–2001 and 2003–2008). They showed that despite the significant drop in road trauma in general, there was no change in the incidence and mortality of SCIs. There were actually more cervical SCIs seen in the more recent period. Cervical spine injuries increased significantly among pedestrians, cyclists and motorcyclists whereas among car users they dropped. This is contrary to our study since we found that the fatal CSI number decreased among pedestrians and remained quite stable among cyclists. The total number of fatal CSI accidents with motorbikes is quite low (n=65) and its incidence remained stable throughout the study. Only 16 motorbike accidents happened to elderly people. Lieutaud et al. also found that those sustaining traffic-related SCI were older than in the past (Lieutaud, Ndiaye et al. 2012). This is corroborated by our study.

Primary prevention policies in traffic that target children and young adults have significantly reduced traffic accidents with CSIs. However, elderly car users and cyclists (especially male) are those who are especially at risk for traffic-related fatal CSIs in Finland. The proportion of elderly people in traffic in general has increased, which partly explains the non-declining trend in the total number of fatal CSIs. Our findings confirm that although the incidence of traffic accidents is in general tending to fall in developed countries, the situation needs to be monitored continuously. Traffic-related primary prevention measures should be also targeted at elderly people and infrastructure planning should be senior-friendly.

We found only a few fatal sports-related CSIs which is contradictory to most of the studies on CSI incidence (Sekhon, Fehlings 2001, Leucht, Fischer et al. 2009, Hasler, Exadaktylos et al. 2012). Even though sports-related CSIs sometimes cause neurological symptoms, they are seldom fatal (Rihn, Anderson et al. 2009), which explains why they are not shown in this study. Moreover, certain sports that may be considered high risk for fatal CSI (such as mountain climbing or base jumping for example) are relatively uncommon in Finland. An autopsy-based retrospective study of all 48,335 fatalities in Hamburg between 1997 and 2006 found 176 sports-related deaths. Of those, 38.1 % were attributed to traumatic causes. The most common traumatic causes were drowning, head trauma and polytrauma. Only one patient died of post-CSI sequalae (Turk, Riedel et al. 2008).

In Finland, jumping head first into shallow water is generally considered as a rather common injury mechanism of CSI in the summer time. Surprisingly, only 11 cases with this type of injury were found during the 24-year study period. As patients with the aforementioned injury mechanism are typically young people, they seem to survive the CSI if they are rescued from water before drowning.

Alcohol is a major risk factor for fatal injuries in general (Tiirikainen 2009). Alcohol played a role in about one third of the cases in our series which is in line with previous series. The share of alcohol intoxicated patients remained more or less the same during the whole study. Young male victims were most often intoxicated. The number of patients who were intoxicated by non-prescription drugs was relatively low (3%) among fatal CSI patients. Unfortunately, non-prescription drugs are getting more common in general in society and therefore the number of accidents related to their abuse may be expected to increase.

6.2 Survival after a CSI

Patients who survive the initial accident and die of sequalae of CSI are general old adults. Due to improved medical care, young and presumably healthier patients often survive the CSI if they manage to reach medical care. Lower survival rates in hospitalized SCI and CSI patients have been described for example among those with old age, high ISS, high level of injury, neurological deficit, and presence of cardiopulmonary resuscitation (Van Den Berg, Castellote et al. 2010, Patel, Smith et al. 2012, Morita, Takebayashi et al. 2017). It is well accepted that recovery from a neurological deficit and survival after SCI is good for young patients. However, patients with high-energy injury mechanisms that cause CSI often die at the scene of accident. Many publications have described how the survival of patients with SCI in developed countries has improved and mortality is not far from the general population (DeVivo, Krause et al. 1999, Van Den Berg, Castellote et al. 2010). However, prehospital deaths are seldom counted in such studies. Like Lieutaud et al. we found that a substantial proportion of patients who die due to sequalae of CSI do so before hospital admission (64.5% of the fatal CSI were not diagnosed before death). Therefore, the survival rates reported by many studies are artificially too high. Epidemiological studies are often based on hospital diagnoses, leaving out patients who die at the scene of the accident or whose injury is missed during hospitalization.

In our study, most of the CSI-related deaths among the young population took place outside of medical facilities (84%, n=727) within the day of injury. Whereas, in the older population, only 44% (n=511) of the deaths occurred outside of medical facilities. Injuries among the young population occurred most often during week-ends whereas for elderly people, injuries were more evenly distributed for each week-day. One third (33%, n=388) of patients in the senior population (60 years and older) died more than seven days post injury. In the majority of these cases (74%), the immediate cause of death was due to respiratory or circulatory diseases (e.g. pneumonia, pulmonary embolism or heart attack). This is an important finding as those are potentially preventable conditions if recognized early. In particular, as the share of elderly patients is increasing among CSI patients. Diminished pulmonary function and cardiovascular diseases have been previously reported with increased mortality among SCI patients (Lemons, Wagner 1994, Van Den Berg, Castellote et al. 2010). As most of the CSI-related deaths in the young population (<60 years) occur immediately, and outside of medical facilities, accident prevention and behaviour modification are crucial to prevent these deaths.

6.3 Challenges of CSI diagnostics

Imaging is a key element in CSI diagnostics. Errors in CSI diagnostics result typically from a lack of suspicion of CSI, inadequate imaging or image misreading. The presence of neck pain or tenderness to palpation of the neck are symptoms commonly present with cervical spine fractures and key components of several clinical decision rules that guide clinical clearance of the cervical spine (Hoffman, Mower et al. 2000, Stiell, Wells et al. 2001). In most cases the selection of patients for cervical spine imaging is easy. However, in clinical practice, we encounter every now and then patients who have experienced failed cervical spine clearance. In retrospect, these diagnostic errors could have been prevented most of the time. While the aforementioned protocols may work well with younger or minimally-injured patients, they can fail for example with older adults. Several recent studies suggest that clinical decision rules are not applicable in geriatric patients (Healey, Spilman et al. 2017, Denver, Shetty et al. 2015, Schrag 2008). According to Shrag et al. (2008) more than half of patients aged 65 years and older who sustained a cervical spine fracture after a fall from a standing or sitting height had no tenderness on clinical examination (Schrag 2008). Healey at al. showed that one-fifth of patients aged 55 years and older with a cervical spine fracture reported no pain on initial presentation and denied tenderness to palpation on examination (Healey, Spilman et al. 2017). While CCR recommends radiological studies on alert and stable patients aged 65 or older where CSI is a concern, Healey et al. suggest that the age limit may be too high to capture patients who require special attention (Healey, Spilman et al. 2017).

We found a considerably high rate of diagnostic errors (14%, n=103) among fatal CSI patients who survived the day of injury. Those who experienced an error were significantly older and the mechanism of injury was more often a fall as compared to patients who did not experience diagnostic errors. Many times, the error resulted from a lack of suspicion of a geriatric CSI (Table 6). Moreover, image misinterpretation and inadequate imaging were seen. Often, only plain radiographs were taken. The limitations of plain radiographs should be acknowledged, and they are meaningful only if they happen to show a CSI. Otherwise, they do not sufficiently rule out a CSI. Some diagnostic errors were due to undiagnosed ligament injuries that possibly could have been diagnosed with MRI. Based on our results, the liberal use of CT in CSI diagnostics is recommended especially among elderly patients (however, the age limit remains elusive). This is also supported by the fact that irradiation side-effects are not a real concern for the elderly.

Surprisingly, the incidence of diagnostic errors did not decrease during the study period from 1987 to 2010 despite advancements in radiological services and increased availability of CT and MRI for CSI diagnostics. Many factors might have contributed to this. First, the number of elderly and presumably more frail people (who are prone to AEs) in society has increased. Also in this study, patients were older towards the end of the study period. Second, a considerable number of the diagnostic errors resulted from a lack of suspicion of CSI (throughout the study period), thus not even plain roentgenograms of the neck were performed. Therefore, the improvement in the CT availability over time could not influence the error rate of the CSI patients. Many times, the trauma (often a fall) has happened a few days or even weeks prior to a physician's appointment and is not acknowledged or asked about by the physician. Third, many death reports from the late 1980's and early 1990's were shorter and less informative than more recent ones, which made it impossible to draw solid conclusions on possible AEs. Therefore, the number of cases in the early years of the study may be artificially lower. Furthermore, an important contributing factor may be the increase in the number of medicolegal autopsies in Finland until 2010 (Official Statistics of Finland 2015 a) (Figure 18). Diagnostic accuracy actually has probably improved over time, but is not seen in this death certificate-based study where medicolegal autopsy was performed on 82.8% of all CSI patients who died after the day of injury. A longitudinal study of autopsies in Switzerland (constant 90% autopsy rate between 1972 and 1992) supports the assertion that the absolute rate of diagnostic errors in general is decreasing over time (Sonderegger-lseli, Burger et al. 2000).

Autopsies are important since there is a high probability that the autopsy will change the perception of the cause of death (Shojania, Burton et al. 2002, Lindsberg, Karjalainen-Lindsberg 2003). Finland has long been known for its high rate of autopsies (especially medicolegal). However, the rate of hospital autopsies has been declining in Finland since the end of the 1970s, and since 2010, the rate of medicolegal autopsies has declined as well (Figure 18). In 2015, medicolegal autopsy was performed for 16% and medical autopsy for 5 % of dead persons (Official Statistics of Finland 2015 a). Feedback from autopsies is an important component of physician training, but the declining number of autopsies performed limits this opportunity. Even though diagnostic errors are inevitable, continuing medical education and quality improvement initiatives might reduce the frequency of some of errors.

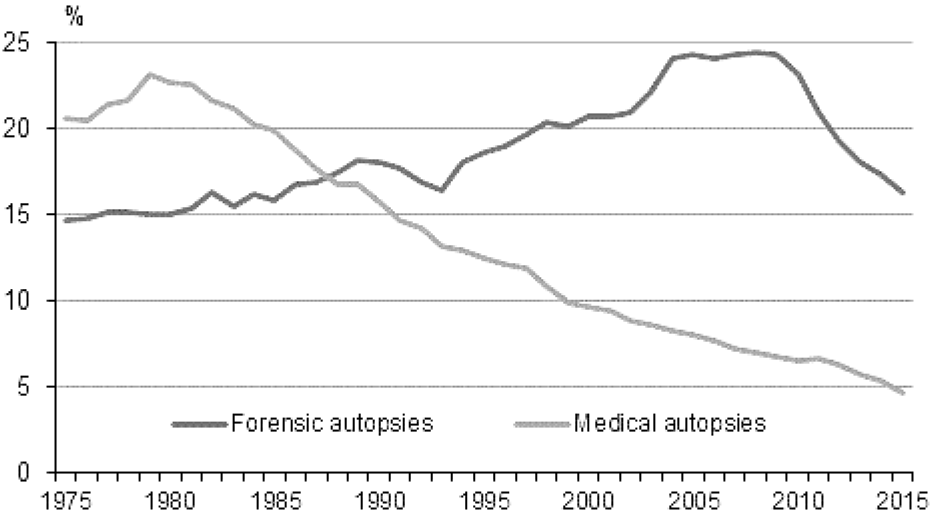


Figure 18. Share of medicolegal (Forensic), and medical autopsies in Finland between 1975 and 2015. Adopted from Official Statistics of Finland (Official Statistics of Finland 2015 a).

6.4 Cervical spine fracture characteristics

The most common site for CSI is the axis (C2) and most often its odontoid process (Goldberg, Mueller et al. 2001). Upper CSIs (C0-C2) are common among elderly patients (Touger, Gennis et al. 2002, Daniels, Arthur et al. 2014, Daffner, Goldberg et al. 1998). The Injury mechanism is typically low-energy coupled with an increasing incidence of osteopenia and degenerative changes. In recent years, the incidence of upper CSIs is increasing worldwide. Young patients are only seldom encountered with upper CSIs in clinical work as compared to elderly patients. High-energy injury to upper cervical spine, if causing CSI, may be fatal due to respiratory arrest. We found that young patients (<60 years) do get these injuries but due to the aforementioned reason are not seen in clinical work very often. In our fatal CSI study (Study I), we showed that 50.6% of patients under 60 years of age have an upper CSI. The majority (91.8%, n=402) died during the day of injury and 96.1% (n=424) had a spinal cord injury. In contrast, in the older group (≥60 years), only about half of the patients sustaining an upper CSI (49.6%, n=194) died during the day of injury, and only 65.3% (n=260) had a spinal cord injury. The difference is most likely due to different accident profiles: high-energy traumas often causing occipitocervical dissociation in young patients and low energy traumas often causing odontoid process fractures of the axis (often not immediately fatal) in older and more fragile patients.

After axis fractures, C6 followed by C7 are the most common sites of cervical spine fractures (Goldberg, Mueller et al. 2001). Vertebral body in the subaxial spine, odontoid process in the axis and arch fracture in the atlas are reported to be the most typical fracture sites within individual vertebrae (Goldberg, Mueller et al. 2001). We studied cervical spine fracture patterns and distributions among HI patients and found for the most part comparable results. In our series C7 was the most commonly injured subaxial vertebra (20%) followed by C6 (17%). The Lateral mass/articular process (32%), lamina (18%) and vertebral body (18%) were the most common fracture locations in the subaxial spine and odontoid process in the axis. In the atlas, comminuted fractures were the most common. Even though it is interesting to know the distribution and types of different kind of fractures, it has only little clinical relevance. More important than to know the precise anatomical location of the fracture is to know the injury stability. Stability along with neurologic function is a major determinant of treatment and prognosis (Anderson, Moore et al. 2007). Several treatment algorithms have been developed for upper and lower CSIs, but few have proven to be both reliable and user friendly (Vaccaro, Koerner et al. 2016). The treatment should be planned on an individual basis taking into account all injury and patient related variables.

6.5 CSI in head-injured patients; comorbidity and risk factors

In general practice, the possibility of cervical spine fracture among CT-positive TBI patients is usually intuitively acknowledged, especially with regard to high-energy injury mechanisms. Our results from Studies III and IV provide further proof for this concept. In the case of HI patients with decreased levels of consciousness (when clinical clearance rules are not operable), head CT combined with cervical spine CT is recommended in the initial phase. In our study, 9.3% of the HI patients who had CT-positive TBI had a cervical spine fracture, whereas in the head CT-negative group 5.7 % of the patients had a fracture. The risk difference, even though clinically significant (p=0.04), is too small to make real difference in clinical work. Cervical spine clearance cannot be done based on head CT status alone and clinical clearance rules still have to be applied whenever possible. As found by the multitude of prior studies, we also found older age to associate with cervical spine fractures among HI patients (Fujii, Faul et al. 2013, Goode, Young et al. 2014).

Even though the association of head injury and CSI is reported by many authors, several studies have published contradictory results (see Table 1). For example, among low-energy injury patients (mean age 65.6 years), Vahldiek et al. (2017) did not find an association between head CT findings and the incidence of CSI (Vahldiek, Thieme et al. 2017). Of the 1,342 patients with blunt minor trauma, only one had a combined injury to the head and cervical spine. In contrast to the sample of Vahldiek et al. our ER sample consisted of HI patients only (HIs ranging in severity from minimal to severe). In our study, patients with cervical spine fractures had more often a high-energy injury mechanism compared to those without such a fracture. However, we did not study the association of CSI and head-CT findings in the low-energy injury population only, as Vahldiek et al. did. Our results indirectly suggest the same as those of Vahldiek et al. since there were actually more spinal cord injuries in the head CT-negative group than in the head CT-positive group (1.5% vs 0.4%, i.e. 12 patients versus one single patient). That is probably due to central cord syndromes after minor falls in the elderly. It seems reasonable to think that low-energy injuries more seldom produce polytrauma than high-energy injuries, and in the former, the association of CT-positive HI and CSI seems to be less prominent. Moreover, the propensity of degenerative spine to fracture due to minimal force certainly has its role. Studies showing that elderly patients often have a narrow spinal canal and a stiff spinal column—making them more prone for cervical SCI—support our results. When it comes to clinical TBI severity, we did not find a difference between patients with or without a spine fracture. Facial bone fractures were significantly associated with cervical spine fractures which is also in line with prior literature (Hackl, Hausberger et al. 2001, Lewis, Manson et al. 1985, Mukherjee, Abhinav et al. 2015, Mulligan, Friedman et al. 2010), and reflects a common injury mechanism in both injuries.

Even though it is generally accepted that certain diseases such as osteoporosis or AS increase the risk of fractures in general, we could not identify any associations between cervical fractures and primary diseases as categorized according to the ICD-10. Our relatively small sample size (n=72) of patients with cervical fractures, is probably the main reason why associations could not be identified.

6.6 Study strengths and limitations

The strength of this study is that its first part (Studies I and II) is based on Finnish official cause-of-death statistics which are in practice, 100% complete. In addition, the data was drawn from the entire population of Finland and therefore the numbers and incidences of cases are true descriptions of the entire Finnish population and not cohort-based estimates. Furthermore, the autopsy rates in Finland are considerably higher than in many other western countries which strengthens the results. The study period of almost a quarter century is long and makes it possible to draw conclusions about the changing epidemiology of CSI.

Studies III and IV were based on a relatively large ED sample (n=3,023) of CT-imaged HI patients. The original sample was non-selected and consists of HIs ranging in severity from minimal to severe which is an advantage when applying the results to clinical practice.

This study has some obvious limitations. First, data extraction in Studies I and II was restricted to death certificates that were selected by diagnosis codes. The risk of missing cases is obvious because the failure of some clinicians to take into account the contribution of trauma to subsequent death means that some of the deaths may have been erroneously diagnosed and may therefore remain outside the study sample. This especially applies to fall-induced accidents among the elderly, where the main cause (injury) behind the death may be difficult to infer. We tried to avoid this by including also patients whose related cause of death was a CSI. We also did not include ICD-10 codes T01.0–T06.0 (including multiple trauma to head and neck), so some of the cases (mainly prehospital deaths due to traffic accidents) may have been missed in the data acquisition. Due to these reasons, the number of CSIs reported in Studies I and II may be underestimated. The discrepancy between Studies I and II on the number of patients who died on the day of injury (1,291 in Study I and 1,297 in Study II) is due to a failure in data interpretation. However, it does not influence the conclusions.

Information available from death certificates is limited, which, in some cases, complicated drawing solid conclusions about the death circumstances and possible AEs. This is why the number of PAEs in Study II might be a conservative estimate. Second, the identification and classification of PAEs was susceptible to subjective considerations, and as such, could have introduced bias. Inter-rater reliability was not measured. However, identification and classification of diagnostic errors (that was the main objective of study II) was straightforward in most cases.

In Studies III and VI, the general data in the HI registry had been retrospectively derived from the patient records. There was a relatively high amount of missing relevant information on, for example, alcohol intoxication and GCS scores. This influenced the significance of the results. Second, head CT criteria in minimal, mild and moderate HIs in the ED were based on the Scandinavian guidelines. Apparently, some patients in the sample did not fulfill the Scandinavian CT criteria and were CT-imaged without solid indications. In contrast, possibly some HI patients were missed because they did not undergo CT imaging although they met the criteria. Third, cervical spine fractures were classified by only one researcher, thus, intra-observer bias was not eliminated. Fourth, cervical spine ligament injuries were not systematically assessed with MRI. Most probably, clinically significant CSIs were not missed since our study included patients whose cervical spine was CT-imaged up to one week post-injury and the care of CSIs in the study catchment area is centered on the study hospital. It must be emphasized that data analysis in Studies III and IV concentrated only on fractures and therefore conclusions cannot be drawn about ligament injuries.

6.7 Future prospects

It is expected that the incidence of CSIs will increases in Finland due to the growing number of elderly people. Fall prevention measures should be actively implemented to prevent some of these injuries. However, with advancements in medical care, the incidence of some of the predisposing conditions, such as DISH, AS and degenerative changes may begin to decrease in time, which may decrease the number of geriatric CSIs. Nevertheless, to date, the frequency of these predisposing conditions is not declining. The total alcohol consumption in Finland has slightly decreased in recent years, which hopefully will reduce the number of CSIs. The continuously improving safety features in driving also acts similarly. Future acts to improve traffic safety with regard to CSIs should focus on young people’s week-end driving as most of their injuries happen on Fridays and Saturdays. As the share of elderly people driving is increasing, infrastructure planning should be senior-friendly and driving skills of seniors should be regularly checked.

In CSI diagnostics, education should be targeted especially at medical students, ED – physicians and neurosurgeons to highlight the pitfalls in cervical spine evaluation. Although diagnostic errors are inevitable to some extent, adherence to evidence based guidelines and understanding their limitations, might reduce the number of some of these events. It should be emphasized that the diagnostics of geriatric CSI is challenging, and liberal use of CT is recommended when injury is suspected. Furthermore, the comorbidity of CT-positive HI and cervical spine fracture should be acknowledged.

To date, there is only limited data available on whole population incidence of CSI. In order to investigate the true incidence of CSI in Finland a study that combines death register data and data from the Finnish Hospital Discharge Register should be performed. To study the change in the CSI incidence and the impact of possible preventive measures, further, continuous research is needed. Research should also focus on the prevention of falls among the elderly and on finding pitfalls in CSI diagnostics. In order to identify diagnostic errors and AEs from patient records, artificial intelligence could be increasingly utilized. Asymptomatic CSIs in the elderly trauma population should be studied in a prospective setting.

7 CONCLUSIONS AND MAIN FINDINGS

Based on the present study, the following conclusion can be made.

1. In Finland, the incidence of fatal CSIs increased between 1987 and 2010 and was approximately 19/million/year in the first decade of the 21st century. In recent years, fatal CSIs are most often caused by falling accidents among elderly males. The mean age of patients has dramatically increased during the study period from about 50 to almost 70 years. Alcohol is continuously a major risk factor for CSI.

2. Errors in CSI diagnostics occur despite advances in radiological techniques and in medical care in general. The rate of diagnostic errors is not declining. Hence, CSI diagnostics remain problematic and diagnostic errors may lead to excess harm for the patient. Those who experience diagnostic errors are elderly and the injury mechanism is most often a ground-level fall.

3. Head injury and CSI largely co-exist. When evaluating patients with an acute HI, special consideration should be given to the cervical spine in the case of a positive head CT scan.

4. In head-injured patients, cervical spine fracture should be acknowledged especially among the elderly, patients with facial fractures, and all patients with high-energy injuries. The axis is the most commonly injured cervical vertebra among HI patients.

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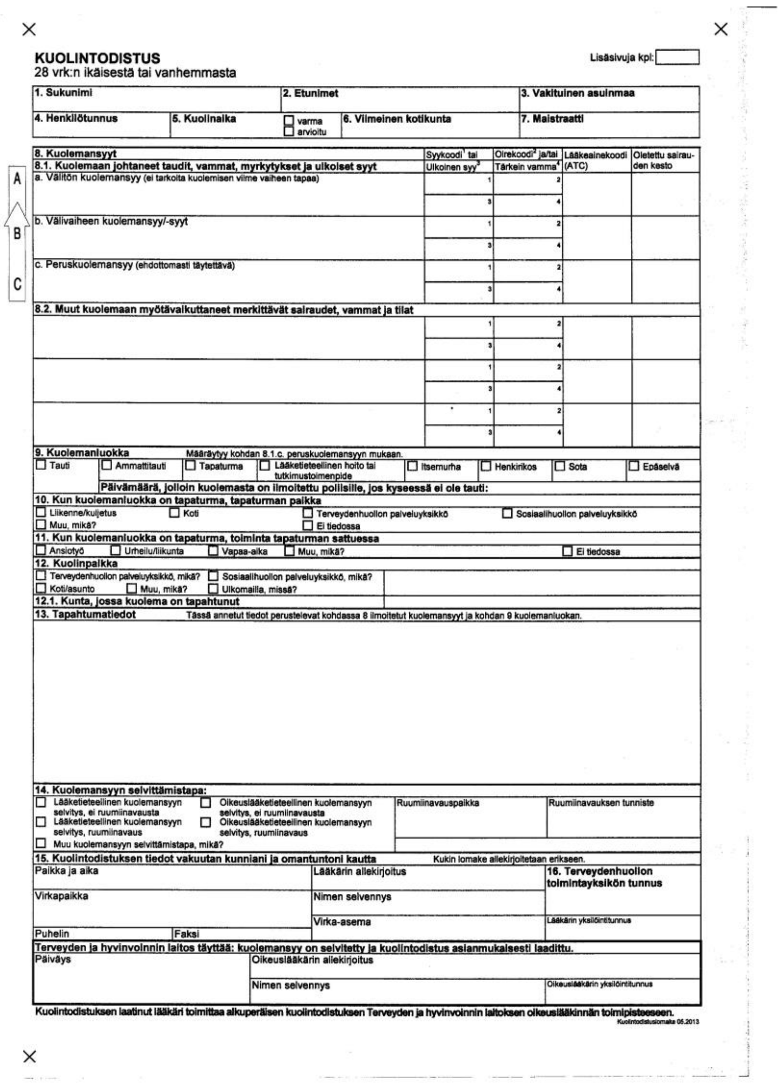
10 APPENDIX

Finnish death certificate (edition 1.1.2014)



KUOLINTODISTUS
28 vrk:n ikäisestä tai vanhemmasta

Lisäsivuja kpl:

1. Sukunimi	2. Etunimet	3. Vakituinen asuinmaa

4. Henkilötunnus	5. Kuolinaika	☐ varma ☐ arvioitu	6. Viimeinen kotikunta	7. Maistraatti

8. Kuolemansyyt 8.1. Kuolemaan johtaneet taudit, vammat, myrkytykset ja ulkoiset syyt	Syykoodi[1] tai Ulkoinen syy[3]	Oirekoodi[2] ja/tai Tärkein vamma[4]	Lääkeainekoodi (ATC)	Oletettu sairauden kesto
A a. Välitön kuolemansyy (ei tarkoita kuolemisen viime vaiheen tapaa)	1 / 3	2 / 4		
B b. Välivaiheen kuolemansyy/-syyt	1 / 3	2 / 4		
C c. Peruskuolemansyy (ehdottomasti täytettävä)	1 / 3	2 / 4		
8.2. Muut kuolemaan myötävaikuttaneet merkittävät sairaudet, vammat ja tilat				
	1 / 3	2 / 4		
	1 / 3	2 / 4		
	1 / 3	2 / 4		

9. Kuolemanluokka Määräytyy kohdan 8.1.c. peruskuolemansyyn mukaan.
☐ Tauti ☐ Ammattitauti ☐ Tapaturma ☐ Lääketieteellinen hoito tai tutkimustoimenpide ☐ Itsemurha ☐ Henkirikos ☐ Sota ☐ Epäselvä
Päivämäärä, jolloin kuolemasta on ilmoitettu poliisille, jos kyseessä ei ole tauti:

10. Kun kuolemanluokka on tapaturma, tapaturman paikka
☐ Liikenne/kuljetus ☐ Koti ☐ Terveydenhuollon palveluyksikkö ☐ Sosiaalihuollon palveluyksikkö
☐ Muu, mikä? ☐ Ei tiedossa

11. Kun kuolemanluokka on tapaturma, toiminta tapaturman sattuessa
☐ Ansiotyö ☐ Urheilu/liikunta ☐ Vapaa-aika ☐ Muu, mikä? ☐ Ei tiedossa

12. Kuolinpaikka
☐ Terveydenhuollon palveluyksikkö, mikä? ☐ Sosiaalihuollon palveluyksikkö, mikä?
☐ Koti/asunto ☐ Muu, mikä? ☐ Ulkomailla, missä?

12.1. Kunta, jossa kuolema on tapahtunut

13. Tapahtumatiedot Tässä annetut tiedot perustelevat kohdassa 8 ilmoitetut kuolemansyyt ja kohdan 9 kuolemanluokan.

14. Kuolemansyyn selvittämistapa:
☐ Lääketieteellinen kuolemansyyn selvitys, ei ruumiinavausta ☐ Oikeuslääketieteellinen kuolemansyyn selvitys, ei ruumiinavausta
☐ Lääketieteellinen kuolemansyyn selvitys, ruumiinavaus ☐ Oikeuslääketieteellinen kuolemansyyn selvitys, ruumiinavaus
☐ Muu kuolemansyyn selvittämistapa, mikä?
Ruumiinavauspaikka | Ruumiinavauksen tunniste

15. Kuolintodistuksen tiedot vakuutan kunniani ja omantuntoni kautta Kukin lomake allekirjoitetaan erikseen.

Paikka ja aika	Lääkärin allekirjoitus	16. Terveydenhuollon toimintayksikön tunnus
Virkapaikka	Nimen selvennys	
Puhelin / Faksi	Virka-asema	Lääkärin yksilöintitunnus

Terveyden ja hyvinvoinnin laitos täyttää: kuolemansyy on selvitetty ja kuolintodistus asianmukaisesti laadittu.

Päiväys	Oikeuslääkärin allekirjoitus	
	Nimen selvennys	Oikeuslääkärin yksilöintitunnus

Kuolintodistuksen laatinut lääkäri toimittaa alkuperäisen kuolintodistuksen Terveyden ja hyvinvoinnin laitoksen oikeuslääkinnän toimipisteeseen.
Kuolintodistuslomake 05.2013

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Clinical Study

Fatal cervical spine injuries: a Finnish nationwide register-based epidemiologic study on data from 1987 to 2010

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Abstract

BACKGROUND CONTEXT: The number of cervical spine injuries (CSIs) is increasing. Cervical spine injuries are associated with high morbidity and mortality. Identifying those who are at risk for CSI-related death can help develop national and international interventions and policies to reduce mortality.

PURPOSE: This study aimed to determine the trends in the incidence and the characteristics of fatal CSIs in Finland over a 24-year study period from 1987 to 2010.

STUDY DESIGN/SETTING: A large nationwide, retrospective, register-based study was carried out.

PATIENT SAMPLE: The population-based sample was collected from death certificates issued in Finland between 1987 and 2010. The death certificates were obtained from the official Cause-of-Death Register, coordinated by Statistics Finland, which covers all deaths occurring in Finland.

OUTCOME MEASURES: Sociodemographics and injury- and death-related data were used for outcome measures.

METHODS: All death certificates issued in Finland (1987–2010) containing a CSI as the cause of death were carefully reviewed.

RESULTS: A total of 2,041 fatal CSIs were identified. These constituted 0.17% of all deaths in Finland within the study period. The average annual incidence of fatal CSIs was 16.5 per million (range: 12.5–21.2). The majority of the victims were male (72.9%) and had concurrent spinal cord injury (83.0%). Traffic accidents (40.1%) and falls (45.0%) were the most common injury mechanisms. Almost one-third (29.8%) of the deaths were alcohol-related. Among the young victims (<60 years) with upper CSI (C0–C2), the majority (91.8%) died within 24 hours post-injury. One-third of elderly victims' (≥60 years) CSI-related deaths occurred after 1 week post-injury and were mostly (74.2%) caused by respiratory and circulatory system diseases. Within the 24-year period, the incidence of fatal CSIs (+2/million), as well as the average age of sustaining a fatal CSI (+13.5 years), increased markedly. Fall-induced accidents among elderly males were the most prominently increasing subpopulation of fatal CSI victims.

CONCLUSIONS: In recent decades, fatal CSI incidence (death certificate-based) has increased, being 18.6 per million in Finland in 2010. Victims of fatal CSIs tend to be older than in the past, and for a substantial number of males, low-energy falls lead to cervical trauma and death.

Keywords: Autopsy; Epidemiology; Mortality; Registries; Spinal injuries; Spinal cord injuries

FDA device/drug status: Not applicable.

Author disclosures: ***TT:*** Nothing to disclose. ***TN:*** Nothing to disclose. ***TML:*** Nothing to disclose. ***JÖ:*** Nothing to disclose. ***AR:*** Nothing to disclose.

No competing financial interests exist.

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Introduction

Globally, traumatic injuries are the leading cause of death among people aged between 5 and 44 years [1]. Cervical spine injuries (CSIs) constitute a considerable number of these fatal injuries. Cervical spine injuries are most often caused by motor vehicle accidents and falls, and they are associated with significant morbidity and mortality [2,3]. The overall prevalence of CSIs among all trauma patients is estimated to be about 3.7% [4], and the annual incidence of CSIs in the general population is reported to be 12 per 100,000 [5,6]. The overall incidence of fatal CSIs in developed countries is not well known. The majority of epidemiologic CSI studies focus on hospital-admitted patients [5–7]. However, it has been noted that a substantial number of all injury-related (including CSI-related) deaths occur outside hospitals [8–10]. Therefore, many CSIs go unrecorded unless postmortem examinations are conducted.

Medicolegal autopsies are crucial for the accuracy of death certification. The number of medicolegal autopsies performed in Finland is considerably higher than in many other developed countries [11]. In Finland, the indications for medicolegal autopsies are strictly controlled by legislation [11]. Medicolegal autopsies are performed in up to 87.2% of all unintentional injury-related deaths, 98.3% of homicides, and 99.5% of suicides [11]. This results in highly controlled and comprehensive national mortality statistics.

Acknowledging the fatal nature of CSIs and the relatively high incidence of concurrent mortality, there is a need for preventive measures for CSIs. Identifying those who are at risk for CSI-related death can help develop national and international interventions and policies to reduce mortality. We aimed to determine the trends in CSI incidence and the characteristics of patients with fatal CSIs over two decades by exploiting the inclusive population-based mortality statistics of Finland. Our data were drawn from the entire population of Finland; therefore, the absolute numbers and incidences of CSIs in this study represent complete population-based results, not cohort-based estimates. We hypothesized that the number of fall-related fatal CSIs among elderly people (60 years and older) had increased over the last two decades.

EVIDENCE & METHODS

Context

The authors present results of an epidemiological investigation regarding the incidence and clinical characteristics of fatal cervical spine injuries in Finland between 1987 and 2010.

Contribution

A total of 2,041 fatal cervical injuries were identified. Fatal cervical injuries have increased over the course of the time-period studied, particularly among older males. Nearly one-third of deaths were alcohol related.

Implications

The results presented here dovetail to some extent with material published from the United States and elsewhere, particularly with respect to an increasing incidence of fatal cervical injury among elderly males. Nonetheless, there is little evidence that the information in this analysis can be generalized beyond the Finnish population and the findings are likely not translatable to other socio-ethnic and demographic contexts, particularly with regard to factors associated with cervical spine injury. While presenting interesting information from the perspective of clinical epidemiology, the evidence associated with this work must be considered no higher than Level IV.

—The Editors

Materials and methods

Study frame and ethics

This population-based sample was collected from death certificates issued in Finland between 1987 and 2010. The death certificates were obtained from the official Cause-of-Death Register, coordinated by Statistics Finland, which covers all deaths occurring in Finland. The Finnish official cause-of-death statistics are, in practice, 100% complete [12]. According to Finnish legislation, a medicolegal autopsy should be performed in the following circumstances: when death is caused or suspected to be caused by (i) a crime, (ii) a suicide, (iii) an accident, (iv) poisoning, (v) an occupational disease, or (vi) medical treatment, or when death has (vii) not been caused by a disease, or when (viii) during the last illness, the deceased had not been treated by a doctor within 3 months, or when (ix) the death was otherwise unexpected. The study was approved by the Ethics Committee of Pirkanmaa Hospital District, Tampere, Finland.

Data collection

All death certificates containing CSI as an immediate, intermediate, main, or related cause of death were carefully reviewed by the first author (T.T.). During this period, both the International Classification of Diseases (ICD)-9 and the ICD-10 codes were in use. In our study, CSI was defined as an injury to the cervical spine, including (i) fractures, (ii) dislocations, (iii) fractures with spinal cord injury, (iv) isolated spinal cord injury, or (v) a combination of the aforementioned. The corresponding ICD-10 diagnosis codes were S12.0, S12.1, S12.7, S12.9, S13.0, S13.1, S13.2, S13.3, S14.0, and S14.1, and the ICD-9 diagnosis codes were 805.0–805.18, 806.0–806.19, 839.0–839.18, and 952.0–952.09. Combined skull and cervical fractures (T01.1–T06.0), whiplash, nerve root injuries, and non-traumatic spinal cord lesions were not used for the screening of the death certificates. The collected variables included diagnosis (ICD codes), gender, age, time of injury, place of injury, time between injury and death, cause of death, type of injury, alcohol and drug consumption at the time of injury, type of death certification, presence of spinal cord injury, and the level of cervical injury. Fractures of the upper cervical spine (C0–C2) were regarded as high injuries and the rest of the cervical fractures (C3–C7) as low injuries. Substance abuse was considered positive if it was mentioned in the death certificate regardless of the method of affirmation.

Statistical analyses

IBM SPSS Statistics 20.0 (IBM Corp. Armonk, NY, USA) was used to perform the analyses. The frequencies and percentage of the analyzed variables were formed using descriptive statistics.

Results

The incidence of fatal CSI in the whole population

The average population of Finland during the 24-year (1987–2010) study period was 5,157,442, and altogether 1,179,305 deaths were reported during that time [12]. In our study, a total of 2,041 death certificates were found to report CSI, and they contributed to 0.17% of all deaths. In the study population, medicolegal autopsy was performed in 1,907 (93.4%) cases and clinical autopsy in 5 (0.2%) cases. In 121 (5.9%) cases, the death certification was written by the treating physician based on clinical findings without an autopsy. In eight (0.4%) cases, the type of death certification was unknown. Cervical spine injury was the main cause of death in 1,847 (90.5%) cases, a related cause of death in 193 (9.5%) cases, and an intermediate cause of death in 1 case. The average annual incidence of fatal CSI was 16.5 per million (range: 12.5–21.2) during the study period. Of all the fatal CSIs, 83.0% (n=1,694) had a cervical spinal cord injury. The average annual incidence of fatal cervical spinal cord injury was 13.7 per million (range: 10.8–16.6).

Characteristics of the study sample

The main characteristics of the study sample are summarized in Table 1. Of all 2,041 CSI victims, 72.9% were male and the overall male-to-female ratio was 2.6:1. The mean age at death was 59.4 years, and 57.3% of the victims were over 60 years old. Ninety-one (4.5%) victims were children (<18 years). Alcohol detection was reported on 608 (29.8%) of the death certificates and its incidence was highest among young males (46.2%). The proportion of spinal cord-injured victims decreased with increasing age (Tables 1 and 2). Among the young victims (<60 years) who had an upper CSI (C0–C2), the majority (91.8%, n=402) died within 24 hours post-injury, and 96.1% (n=424) of these had a spinal cord injury. The mechanism of injury and cause of death varied significantly by age. Young and middle-aged victims (<60 years) were often injured in fatal traffic accidents or in suicides, and older (≥60 years) victims were injured most often in low-energy falls. Sports-related injuries presented only 0.6% of all accidents. There were significant differences in the place of death for age groups. Of the older victims, 74.3% died at their home or residence or in a medical facility, whereas for younger victims, the place of death was coded as "other" (as opposed to "medical facility," "home or residence," or "abroad") in 71.9% of cases. The mean time between injury and death was 46.7 days (median: 0 days, min: 0 days, and max: 37.9 years). This time was much shorter among younger victims since 86% of them died within 24 hours post-injury, whereas only 48% of the older (≥60 years) victims died during the day of injury. A substantial number of older victims (n=388, 33.2%) died after 1 week post-injury. Among those, the immediate causes of death were provided in 93.0% (361/388) of cases and were most often diseases of the respiratory system (n=234, 60.3%) and diseases of the circulatory system (n=54, 13.9%). Respiratory system diseases mostly included pneumonia (n=216, 55.7%), whereas any kind of heart disease (n=27, 7.0%), stroke (n=13, 3.4%), and pulmonary embolus (n=12, 3.1%) accounted for the majority of the circulatory system diseases. Most of the injuries happened in July (10.1%), and the most frequent day of the week for injury was Saturday (18.0%).

Changes in the characteristics of the fatal CSI victims during the study period

The death certificate-based number and incidence of CSI victims began to increase at the end of 1990s (Fig. 1), and they have been on average 99.8 and 19.0 per million, respectively, during the last 10 years (2001–2010) of the study period. Fig. 2 shows the clear increase in the mean age at the time of death—from 54.4 years to 67.9 years—during the study period. The changes in the frequency of the most common injury types are shown in Fig. 3. The number of fall-related CSIs exceeded traffic accident-related CSIs in 1998. The increase in the total number of CSI victims is explained by the increase in fall-related accidents of elderly males, which is shown in Fig. 4, Top. The number of pediatric patients decreased toward the end of the study period (Table 2).

Discussion

In this nationwide cause-of-death register-based epidemiologic study, we used the death certificates of the entire Finnish population to describe the trends in the incidence and characteristics of fatal CSI victims. Between 1987 and 2010, we found 2,041 deaths that were related to CSI. The average incidence of fatal CSI in Finland was 16.5 per million. We have shown that the number and incidence of CSI-related deaths increased, especially after the year 1999, and during the last 10 years, there have been about 100—or 19 per million—annually. Falls, traffic accidents, and suicides were the leading causes of injury.

The causes of injury and the age of those deceased changed notably during the observation period. The mean age at the time of death increased from 54.4 years to 67 years, and the number of pediatric patients decreased significantly. Falls exceeded traffic accidents as the most common cause of injury

Table 1
Patient and injury characteristics of the 2,041 fatally cervically injured victims in Finland over the 24-year follow-up period (1987–2010)

	All	Under 60 years	60 Years and older
Number of patients, n (%)	2,041	871 (42.7)	1,170 (57.3)
Gender, n (%)			
Female	554 (27.1)	218 (25)	336 (28.7)
Male	1487 (72.9)	653 (75)	834 (71.3)
Age at death, mean±SD (years)	59.4±23	36.9 (15.5)	76.2 (9.1)
Female	61.4±25.2	34.4 (16.8)	78.9 (9.2)
Male	58.7±22.1	37.7 (15)	75.1 (8.9)
Alcohol mentioned, n (%)	608 (29.8)		
Female	82 (14.8)	53 (24.3)	29 (8.6)
Male	526 (35.4)	302 (46.2)	224 (26.9)
Drugs mentioned, n (%)			
Female	14 (2.5)	15 (2.5)	16 (2.5)
Male	49 (3.3)	38 (5.8)	11 (1.3)
Spinal cord injury, n (%)			
Female	441 (79.6)	207 (95.0)	234 (69.6)
Male	1253 (84.3)	620 (94.9)	633 (75.9)
Cause of injury, n (%)			
Fall	919 (45)	143 (16.4)	776 (66.3)
Ice	14 (0.7)	2 (0.2)	12 (1.0)
Same level	415 (20.3)	25 (2.9)	390 (33.3)
From bed	28 (1.4)	0	28 (2.4)
Stairs	204 (10.0)	50 (5.7)	154 (13.2)
Ladder	13 (0.6)	2 (0.2)	11 (0.9)
Diving into water	11 (0.5)	10 (1.1)	1 (0.1)
>1 meter	96 (4.7)	35 (4.0)	61 (5.2)
Unspecified	138 (6.8)	19 (2.2)	119 (10.2)
Traffic	828 (40.1)	511 (58.7)	317 (27.1)
Pedestrian	106 (5.2)	59 (6.8)	47 (4.0)
Bicycle	110 (5.4)	52 (6.0)	58 (5.0)
Motorbike	65 (3.2)	49 (5.6)	16 (1.4)
Car	501 (24.5)	327 (37.5)	174 (14.9)
Off-road motor vehicle	7 (0.3)	5 (0.6)	2 (0.2)
Water transport	2 (0.1)	2 (0.2)	0
Aircraft	3 (0.1)	3 (0.3)	0
Unspecified	34 (1.7)	14 (1.6)	20 (1.7)
Assault	34 (1.7)	27 (3.1)	7 (0.6)
Firearm	15 (0.7)	14 (1.6)	1 (0.1)
Other	19 (0.9)	13 (1.5)	6 (0.5)
Event of undetermined intent (firearm)	3 (0.1)	3 (0.3)	0
Event of undetermined intent (other)	21 (1.0)	13 (1.5)	8 (0.7)
Suicide	178 (8.7)	156 (17.9)	22 (1.9)
Other traumatic	43 (2.1)	16 (1.8)	27 (2.3)
Unspecified	15 (0.7)	2 (0.2)	13 (1.1)
Cause of death, n (%)			
Disease	188 (9.2)	16 (1.8)	172 (14.7)
Occupational disease	2 (0.1)	0	2 (0.2)
Accident	1605 (78.6)	649 (75.0)	956 (81.7)
Medical treatment	2 (0.1)	0	2 (0.2)
Suicide	178 (8.7)	156 (17.9)	22 (1.9)
Homicide	34 (1.7)	27 (3.1)	7 (0.6)
Unknown	32 (1.6)	23 (2.6)	9 (0.8)
Accident subclassification, n (%)			
Traffic	783 (48.8)	493 (76.0)	290 (30.3)
Occupation	32 (2.0)	23 (3.5)	9 (0.9)
Sport	9 (0.6)	6 (0.9)	3 (0.3)
Leisure	103 (10.8)	36 (5.5)	67 (7.0)
Home	417 (25.0)	40 (6.2)	377 (39.4)
Medical facility	58 (3.6)	3 (0.5)	55 (5.6)
Other	150 (9.3)	37 (5.7)	113 (11.8)
Unknown	47 (2.9)	10 (1.5)	37 (3.9)
Missing	6 (0.4)	1 (0.2)	5 (0.5)
Place of death, n (%)			
Medical facility	805 (39.4)	146 (16.8)	659 (56.3)
Home or residence	290 (14.2)	79 (9.1)	211 (18.0)
Other	921 (45.1)	628 (71.9)	295 (25.2)
Abroad	25 (1.2)	20 (2.3)	5 (0.4)
Cervical spine, injury level, n (%)			
C0–C2 injury	839 (41.1)	441 (50.6)	398 (34)
C3–C7 injury	1202 (58.9)	430 (49.4)	772 (66)
Time since injury to death, mean±SD (days)	46.7±497	38.4±553	54.6±451
Time since injury to death, number of patients, n (%)			
<24 hours	1291 (64.3)	741 (86)	550 (48)
1–7 days	248 (12.4)	41 (4.8)	207 (18.1)
8–30 days	212 (10.6)	37 (4.3)	175 (15.2)
31 days–1 year	226 (11.3	37 (4.3)	189 (16.5)
>1 year	30 (1.5)	6 (0.7)	24 (2.1)
Data missing	34 (1.7)		

Table 2
Total number of CSI cases per 10-year age group, proportion of spinal cord injury victims, and comparison of the number of cases between the years 1987–1995 and 2002–2010 (the first and last nine years of the study period)

Age group (years)	Total number of CSI victims, n (%)	Proportion of spinal cord-injured victims, n (%)	Number of CSI victims between 1987 and 1995, n (%)	Number of CSI victims between 2002 and 2010, n (%)	Change between 1987–1995 and 2002–2010, n (%)
0–9.9	41 (2.0)	40 (97.6)	26 (4.0)	5 (0.6)	−21 (−80.8)
10–19.9	100 (4.9)	99 (99)	47 (7.2)	25 (2.8)	−22 (−46.8)
20–29.9	183 (9.0)	178 (97.3)	75 (11.4)	70 (7.8)	−5 (−6.7)
30–39.9	142 (7.0)	141 (99.3)	67 (10.2)	41 (4.6)	−26 (−38.8)
40–49.9	170 (8.3)	155 (91.2)	57 (8.7)	66 (7.4)	9 (+15.8)
50–59.9	235 (11.5)	214 (91.2)	65 (9.9)	98 (11.0)	33 (+50.8)
60–69.9	355 (17.4)	299 (84.2)	118 (18.0)	152 (17.0)	34 (+28.8)
70–79.9	395 (19.4)	313 (79.2)	115 (17.5)	187 (20.9)	72 (+62.6)
80–89.9	338 (16.6)	217 (62.2)	81 (12.3)	188 (21.1)	107 (+132.1)
90–99.9	82 (4.0)	38 (46.3)	6 (0.9)	61 (6.8)	55 (+916.7)
Total	**2,041 (100%)**	**1,694 (83.0)**	**657 (100)**	**893 (100)**	**236 (+35.9)**

in 1998. Elderly people's low-energy falls accounted for most of the increase in the total number of CSI-related deaths. The number of elderly individuals' fall-induced accidents started to increase at the end of the 1990s. Previously, it has been reported that even though in general, falling accidents are more frequent in the female population, most of the fall-induced severe CSIs occur in the male population [13,14]. Our results are in line with recent findings, because we found that 71.3% of the elderly injured (≥60 years) were male (Table 1, Figs. 1 and 4). The reason for this phenomenon is unknown. It has been proposed that men are at greater risk for severe falls than women [14].

Most of the fall-induced accidents were simple ground-level falls and only 14 (0.7%) cases happened on ice (Table 1). Most of the falls happened during the summer months, and a large number happened on stairs. It may be hypothesized that winter conditions are not likely a strong risk factor for fatal CSI.

Interestingly, although the overall incidence of accident-related deaths has been quite stable in Finland over the last decades, the incidence of fatal CSI has increased. The same phenomenon has been reported by Kannus and colleagues in the Finnish geriatric population [14]. In our study, the number of fatal CSIs in the older population showed a remarkable increase, whereas the younger population showed a clear decrease during the study period (Table 2). The proportional increase in the number of fatal CSI victims was greatest in the oldest age group (90–100 years). The increase in the number of fatal CSI victims in the older population cannot be explained by demographic changes alone. One possible

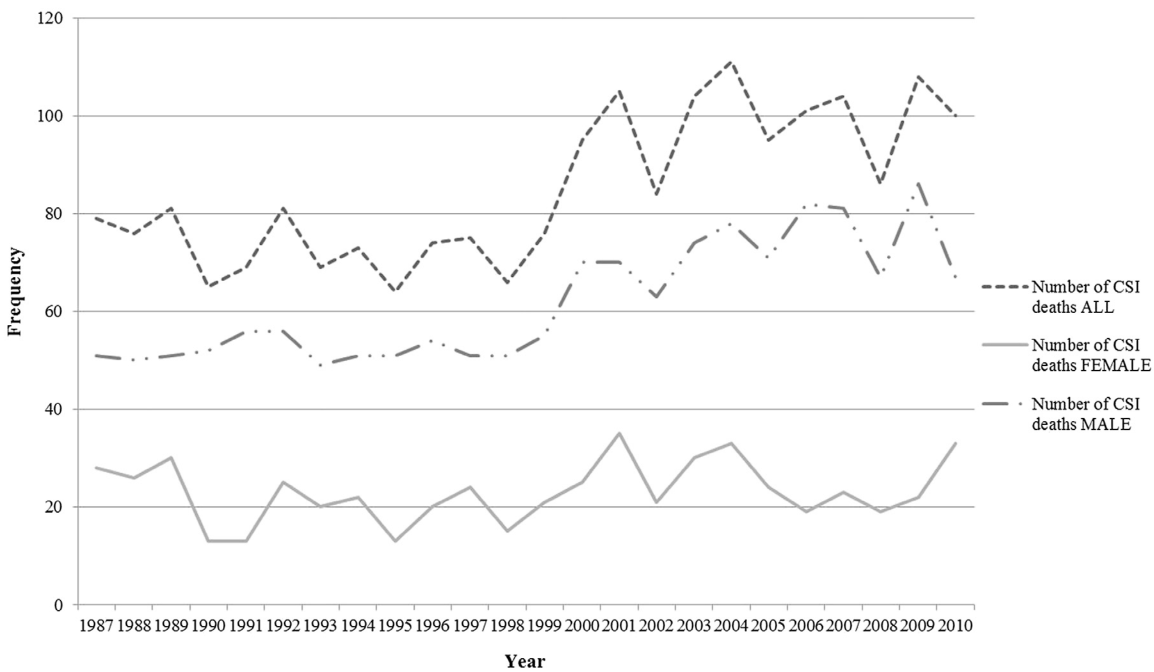

Fig. 1. Number of cervical spine injury (CSI)-related deaths by year.

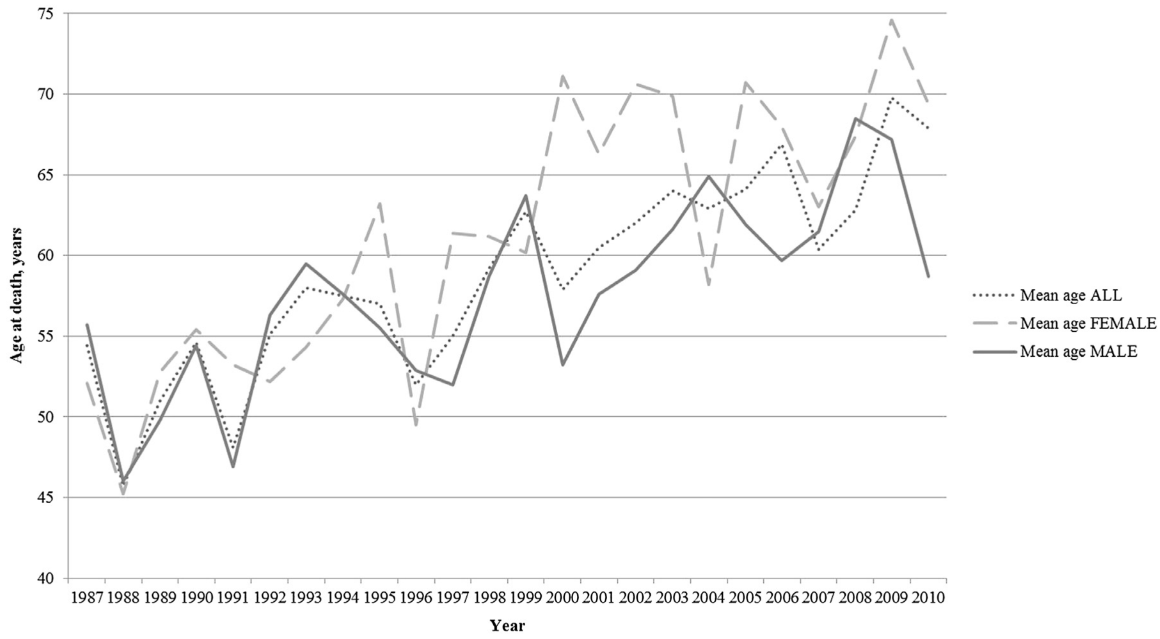

Fig. 2. Mean age at death by year.

reason might be the increase of spondylosis changes in the spine with age.

Moreover, Lieutaud and colleagues observed that even though the total number of road traffic accidents has fallen in recent years, the incidence and mortality of spinal cord injuries sustained in those accidents has not shown significant reduction [15]. These patients also tended to be older than in the past and more often had associated multiple trauma [15]. Our results support this finding because in Finland, road traffic mortality decreased from 581 per year to 272 per year between 1987 and 2010 [12]. During the same period, fatal CSIs induced by traffic accidents decreased only marginally (Fig. 3). Sports have been reported to be a significant cause of cervical injury in previous epidemiologic reports [2,3,7]. For example, in a multicenter cohort study from 1988 to 2009 by Hasler and colleagues, 7.6% of cervical injuries were due to sports-related accidents. Surprisingly, in our series, sports-related injuries were almost totally absent, with only 9 (0.4%)

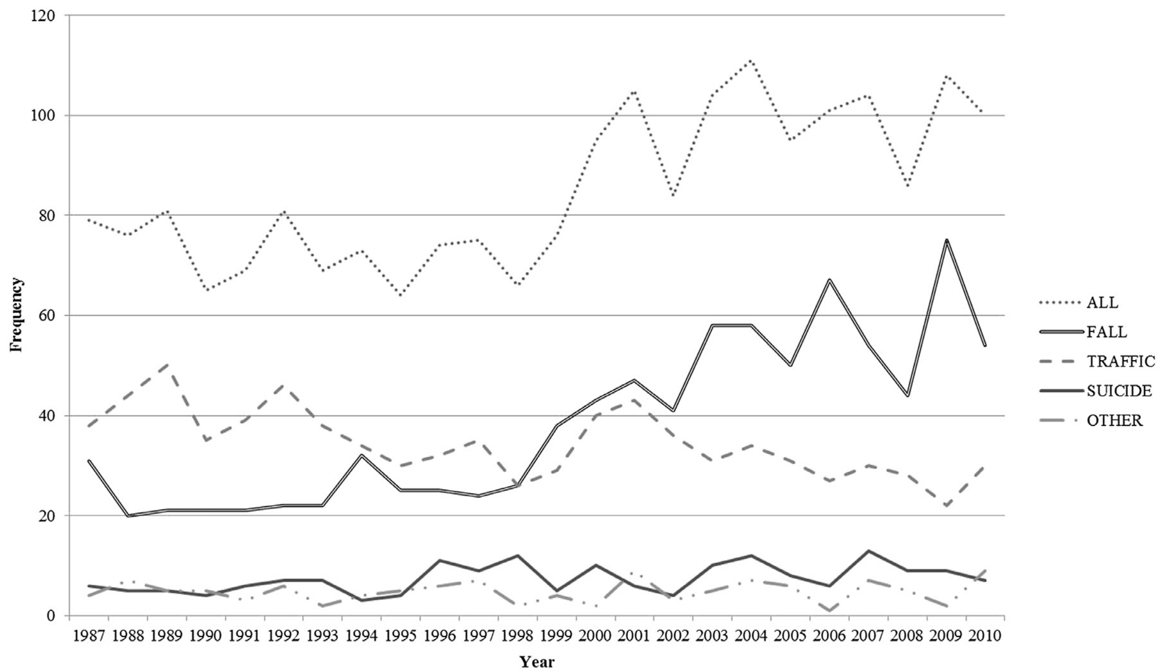

Fig. 3. Number of cervical spine injury (CSI)-related deaths by injury mechanism by year.

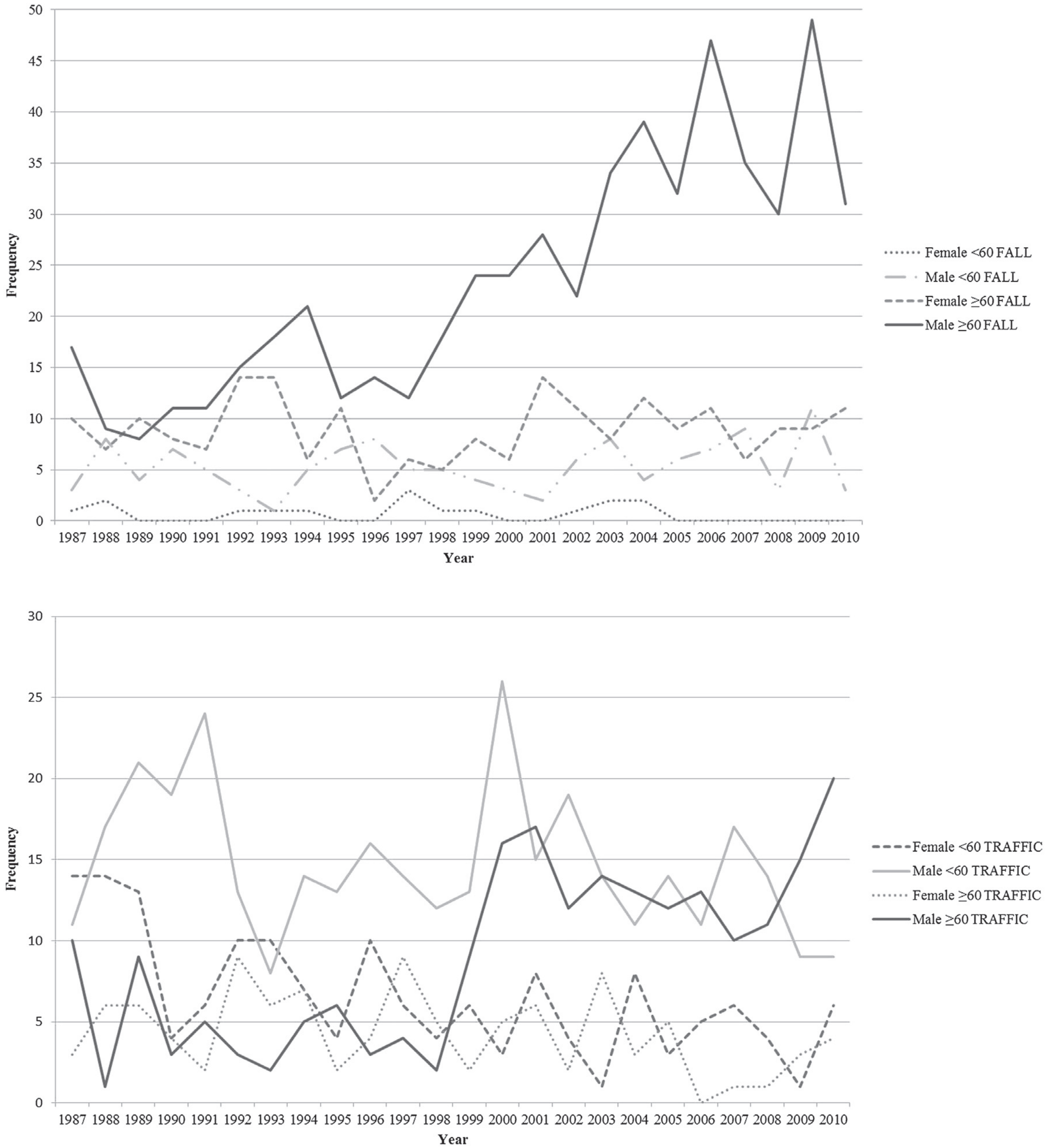

Fig. 4. (Top) Number of cervical spine injuries (CSIs) caused by fall-induced accidents by year in <60- and ≥60-year-old victims. (Bottom) Number of CSI injuries caused by traffic accidents by year in <60- and ≥60-year-old victims.

cases present. The reason for this difference may lie in the divergent coding habits between studies, as some of the sports injuries may have been coded as leisure activity injuries in our series.

Alcohol is a major risk factor for CSI [2,16], and in general, every third fatal injury in Finland occurs under the influence of alcohol [17]. Our findings corresponded with previous reports, since alcohol was mentioned in 29.8% of all cases and in 46.2% of young (<60 years) male victims.

The incidence of cervical spinal cord injury in the setting of CSI is reported to be 10%–50% [3,6,18]. We found a spinal cord injury in 83% of all victims and in 91.2% of those who died in less than 24 hours. Among the young victims (<60 years) who had an upper CSI, the majority (91.8%, n=402) died within 24 hours post-injury, and 96.1% (n=424) of these victims had a spinal cord injury. On the contrary, in the older group (≥60 years), only about half of the victims sustaining an upper CSI (49.6%, n=194) died in less than 24 hours, and 65.3% (n=260) of these had a spinal cord injury. The difference is most likely due to different accident profiles: high-energy traumas often causing occipitocervical dissociation in young patients and low energy traumas often causing C2 dens fracture (often not immediately fatal) in older patients.

The epidemiology of traumatic deaths in general has been studied extensively. In 1977, Baker and colleagues described the classic trimodal distribution of trauma deaths, where the first peak represented the immediate deaths, the second peak included early hospital deaths, and the third peak included late deaths [19]. The trimodal distribution has later been challenged, for example, by Sauaia and Evans [8,9]. Evans and colleagues found that in Australia, 66% of patients die before hospitalization and only 2% die after 7 days. They also reported that none of the low-energy trauma patients (who had all sustained a fall of less than 1 m) died before hospitalization. Our results for CSI victims differ, because we found that 460 (22.9%) of all CSI victims and 388 (33.2%) of the older group (≥60 years) died after 7 days. Furthermore, 147 of 457 (32.2%) low-energy trauma deaths occurred in less than 24 hours post-injury. The majority (97%) of the deaths that occurred in less than 24 hours post-injury were prehospital deaths.

Most of the CSI-related deaths among the young population take place outside of medical facilities within 24 hours post-injury. Therefore, accident prevention and behavior modification is crucial in reducing the number of victims in this subgroup. In the older population, one-third (n=388, 33.2%) of the CSI-related deaths occur more than 7 days post-injury. In 74.2% of these cases, the immediate cause of death was either due to diseases of the respiratory or the circulatory system (including eg, pneumonia, heart attack, and pulmonary embolism). This is important, as these are potentially preventable or treatable medical conditions if they are recognized early. A fortiori, as the proportion of elderly population among CSI victims is steadily increasing.

Identifying those who are at risk for a cervical injury-related death can help in developing interventions and policies intended to reduce the mortality among this patient group. We studied all victims who had sustained a fatal CSI—either with or without a spinal cord injury—coded in their death certificates. The strength of the present study is that it is based on the whole population of one nation over an observation period of 24 years. Moreover, it has been shown that the quality and rate of performed medicolegal autopsies in Finland is among the highest in the world [11].

Limitations of the study

We based our study on death certificates that were selected by diagnosis codes. This method carries a risk of missing cases. It has been shown that because of the failure of some clinicians to take into account the contribution of trauma to subsequent death, some of the deaths may have been erroneously diagnosed and may therefore remain outside our sample [10,20]. This especially applies to fall-induced accidents among the elderly. In the present study, we tried to avoid this by also assessing the related cause of death. We did not include ICD-10 codes T01.0–T06.0 (including multiple trauma to head and neck), so some of the cases (mainly prehospital deaths due to traffic accidents) may have been missed. Due to the aforementioned reasons, the number of CSIs reported in our study may be underestimated. It must also be noticed that in those 193 (9.5%) death certificates that reported CSI as a related cause of death, cervical injury by itself was not necessarily fatal but a contributing factor to the following death.

Conclusions

During the 24-year observation period, fatal (death certificate-based) CSI incidence has increased. In 2010, the population-based incidence of CSI in Finland was 18.6 per million. This study highlights that victims of CSI tend to be older than in the past, and a substantial number of cervical traumas and deaths result from low-energy falls by males.

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Title: Preventable diagnostic errors in fatal cervical spine injuries: a nationwide register-based study from 1987 to 2010

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Preventable diagnostic errors in fatal cervical spine injuries: a nationwide register-based study from 1987 to 2010

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Abstract

Background: Fall-induced injuries in patients are increasing in number and they often lead to serious consequences, such as cervical spine injuries (CSI). CSI diagnostics remain a challenge despite improved radiological services.

Purpose: Our aim is to define the incidence and risk factors for diagnostic errors among patients who died following a CSI.

Study Design/Setting: Retrospective death certificate-based study of the whole population of XXX.

Patient sample: We identified 2,041 patients whose death was, according to the death certificate, either directly or indirectly caused by a CSI.

Outcome measures: Demographics, injury- and death-related data, and adverse event-related data.

Methods: All death certificates between the years 1987 and 2010 from Statistics XXX that identified a CSI as a cause death were reviewed to identify preventable adverse events (PAE) with the emphasis on diagnostic errors.

Results: Of the 2,041 patients with CSI-related deaths, 36.5% (n=744) survived at least until the next day. Errors in CSI diagnostics were found in 13.8% (n=103) of those who died later than the day of injury. Those with diagnostic errors were significantly older (median age 79.4 years, 95% CI 75.9-80.1 vs. 74.9, 95% CI 70.2-72.9, p<0.001) and the mechanism of injury was significantly more often a fall (86.4%, n=89 vs. 69.7%, n=447, p=0.002) compared to those who did not have a diagnostic error. The incidence of diagnostic errors increased slightly during the 24–year study period.

Conclusions: Cervical spine injury diagnostics remain difficult despite improved radiological services. The majority of the patients subjected to diagnostic errors are fragile elderly people with reduced physical capacity. In our analysis, preventable adverse events and diagnostic errors were most commonly associated with ground-level falls.

Key Words: Spinal Injuries; Diagnostic Errors; Adverse Effects; Causes of Death; Accidental Falls

Introduction

Cervical spine injury (CSI) is a potentially devastating injury. Approximately 2-4% of blunt trauma patients suffer CSI.(1-4) Falls are common in the elderly, and elderly patients may sustain a CSI after a seemingly low energy trauma—including ground-level falls.(5, 6) It is estimated that 30% of people aged 65 or older fall every year,(7, 8) and about 5-10% of falls lead to serious injuries.(9, 10) The incidence of fall-related CSIs among older adults has increased since the 1970´s.(6, 11) Patients aged 65 years or older have a relative risk for CSI twice that of younger trauma patients.(12, 13) The associated mortality rate in this age group is approximately 24%.(14, 15) About 10%–50% of patients with CSIs suffer a concomitant spinal cord injury, which may lead to complete or incomplete tetraplegia or death.(16-18) Nevertheless, isolated CSIs without a spinal cord injury lead to high mortality among elderly.(19, 20)

The detection of CSI is especially challenging among the elderly, patients with alterations in consciousness, or patients with distracting injuries.(13, 21) The gold standard of both pre-hospital and in-hospital trauma care is cervical spine immobilization to prevent further neurological deterioration.(15, 19, 22) Emergency cervical spine computed tomography (CT) is the cornerstone of CSI diagnostics in order to triage the need for immediate care. Failure to suspect or detect a CSI as early as possible leads to increased morbidity and mortality.(20, 23, 24) Diagnostic errors occur in every medical specialty. The error rate in clinical medicine is estimated at 5-15%.(25, 26) In blunt trauma patients, accurate confirmation of the absence of CSI remains a challenge despite clinical decision rules and sophisticated radiological techniques.(21, 27-32) Historically, in the era of plain roentgenograms, misdiagnosis of a CSI was estimated in up to one-third of cases.(17, 20, 24, 33) Currently, in the era of CT, the rate of misdiagnosis is reported to range from approximately 0 to 5% depending on the population studied,(33, 34) and a failure to identify a CSI is considered a diagnostic error. These diagnostic errors might result in fatal adverse events (AE). An AE is usually defined as an unintended injury or complication, caused by health care management rather than the patient's underlying disease. These events result in prolonged hospital stay, disability at the time of discharge, or death.(35-37) In this study, diagnostic errors were considered as AEs regardless of their consequences. AEs may or may not be considered preventable (PAEs = preventable adverse events). PAEs include preventable diagnostic errors, medical errors, and so-called iatrogenic errors. In general, the incidence of in-hospital AEs is estimated around 10% of which a substantial proportion are considered preventable.(38, 39) In surgical and orthopedic care the rate of AEs is even greater (up to 30%), of which the majority are considered preventable.(40-43)

The primary purpose of this nationwide retrospective study was to define the incidence and characteristics of CSI diagnostic errors (only diagnostic errors that were considered preventable were included), in patients whose death was directly or indirectly related to a CSI according to their death certificates. The secondary aim was to define the incidence and characteristics of other kinds of PAEs (other than diagnostic errors). We hypothesized that the number of preventable errors in CSI diagnostics decreased over the years (from 1987 to 2010) due to improved radiological services and more objective diagnostics.

Materials and Methods

This population-based sample was collected from death certificates issued in XXX between 1987 and 2010. The death certificates were obtained from the official Cause-of-Death Register, coordinated by Statistics XXX (XXXX, XXXX), which has filed each death certificate in XXX since 1936.(44) The XXX official cause-of-death statistics are, in practice, 100% complete.(44) Medicolegal autopsies are crucial for the accuracy of death certification. The number of medicolegal autopsies performed in XXX is considerably higher than in many other developed countries.(45) In XXX, the indications for medicolegal autopsies are strictly controlled by legislation.(45) Medicolegal autopsies are performed in up to 87.2% of all unintentional injury-related deaths, 98.3% of homicides, and 99.5% of suicides.(45) According to XXX legislation, a medicolegal autopsy should be performed in the following circumstances: when death is caused or suspected to be caused by (i) a crime, (ii) a suicide, (iii) an accident, (iv) poisoning, (v) an occupational disease, or (vi) medical treatment, or when death has (vii) not been caused by a disease, or when (viii) during the last illness, the deceased had not been treated by a doctor within 3 months, or when (ix) the death was otherwise unexpected. Each death certificate includes among other information a short narrative that contains additional relevant information (including key findings from autopsy) on the circumstances leading to death. All relevant information on the events leading to a patient's death are supposed to be summarized in the death certificates. At the National Institute for Health and Welfare (XXX,XXX), forensic pathologists review each death certificate and ensure that the recorded causes of death are accurate, complete, and consistent.(44) This process results in highly controlled and comprehensive national mortality statistics. The main/underlying cause of death is the disease or injury that initiated the series of illnesses leading directly to death. The immediate cause of death refers to the disease, failure, or injury that causes the person to die. The intermediate cause of death refers to the condition that arise from or after the main/underlying cause to become the immediate cause of death. The related causes of death are other significant circumstances that contributed to the death.(44) This study was approved by the Ethics Committee of XXXX Hospital District, XXXX, XXXX.

Data Collection

In the first stage of the study, all death certificates containing CSI as an immediate, intermediate, main, or related cause of death were reviewed carefully by the first author (TT). During the study period, both the 9th and 10th Edition of the International Statistical Classification of Diseases and Related Health Problems (ICD-9 and ICD-10) were in use. In our study, CSI was defined as an injury to the cervical spine, including (i) fractures, (ii) dislocations, (iii) fractures with spinal cord injury, (iv) isolated spinal cord injury, or (v) a combination of those injuries. The corresponding ICD-10 diagnosis codes were: S12.0, S12.1, S12.2, S12.7, S12.9, S13.0, S13.1, S13.2, S13.3, S14.0, and S14.1. Similarly, the ICD-9 diagnosis codes were: 805.0–805.18, 806.0–

806.19, 839.0–839.18, and 952.0–952.09. Combined skull and cervical fractures (T01.1–T06.0), whiplash, nerve root injuries, and non-traumatic spinal cord lesions were not used for the screening of the death certificates. The collected variables included diagnosis (ICD codes), gender, age, time of injury, place of injury, time between injury and death, cause of death, type of injury, alcohol and drug consumption at the time of injury, type of death certification (medicolegal autopsy, hospital autopsy, autopsy not performed, or other), presence of spinal cord injury, and approximate level of cervical injury. Injuries at cervical levels C0-C2 were regarded as high injuries and injuries at levels C3-C7 as low injuries. Cases where the level of injury was undetermined or the injury consisted of multiple levels were considered as low injuries. Substance abuse was considered positive if it was mentioned in the death certificate regardless of the method of verification.

In the second stage of the study, all cases in which the date of death was different from the date of injury were selected for further analysis. By doing the selection we excluded people who, in majority of cases, succumbed at the accident scene and therefore had a minor chance for PAE. The death reports of those who survived at least until the next day were examined (by XXXX and XXXX) to detect reports with a suspicion of any kind of PAE (including preventable diagnostic errors and other medical errors). Preventability was defined as care that fell below the level of expected performance for practitioners or systems at the time of the PAE. If the death report did not provide enough information for a solid conclusion, it was considered as a non-PAE or a PAE undetermined. PAEs were categorized in two main groups (diagnostic errors and other events) and six subcategories (surgical treatment related events, diagnostic errors, health care facility related events, secondary complications, treatment-related events, and other). The location of the PAE occurrence was documented. If more than one PAE was detected for an individual patient, only the most severe one was coded. The focus of the current study was on preventable diagnostic errors.

Patient Involvement

Patients were not involved in setting the research question or the outcome measures, nor were they involved in the design, or implementation of the study. No patients were asked to advice on interpretation or writing up of results. There are no plans to disseminate the results of this research to study participants or the relevant patient community.

Statistical Analyses

IBM SPSS Statistics 20.0 (IBM Corp. Armonk, NY, USA) was used to perform the analyses. The frequencies and percentage of the analyzed variables were calculated using descriptive statistics. The normality of the variable distributions was tested using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Continuous variables were analyzed with the Pearson (normal distribution) and Spearman (skewed distribution) correlation coefficients. Group comparisons were tested with the Student's t-test (normal distribution) and the Mann-Whitney U-test (skewed distribution). The statistical significance level was set at $p < 0.05$.

Results

A total of 2,041 death certificates reported a CSI in XXXX during the 24-year study period (1987-2010). The average population of XXX during the same time was about five million. Of the 2,041 CSI-related deaths, 36.5% (n = 744) survived at least until the next day (date of death was later than date of injury). The differences in patient characteristics of those who died on the day of injury and those who died after the day of injury are presented in Table 1. Those who died on the day of injury were significantly younger (median age = 55.0 years) and the most common injury mechanism was a traffic accident (51.7%, n = 670) whereas those who survived at least until the next day were elderly (median age = 75.7 years) and the injury mechanism was usually a fall (72.0%, n = 536). The location of death for those who survived at least until the next day was a medical facility in 93.8% (n = 698), whereas only 8.2% (n = 107) of those who died on the day of injury did so in a medical facility. Medicolegal autopsies were performed in 99.5% (n = 1,291) of the patients who died on the day of injury and in 82.8% (n = 616) of those who survived at least until the next day. Of those who survived at least until the next day, a PAE was identified in 27.7% (n = 206), of which half (n = 103) were considered diagnostic errors (Fig 1). In 5% (n = 37), a PAE could not be determined as present or not present.

Insert Figure 1 here

Insert Table 1 here

Preventable Diagnostic Adverse Events

Patient characteristics, injury-related information, and diagnostic error data are presented in Table 2. CSI patients with diagnostic errors were significantly older (median age 79.4 years, 95% CI 75.9-80.1 versus 74.9, 95% CI 70.2-72.9, $p<0.001$), and the injury mechanism was significantly more often a fall (86.4%, n=89 versus 69.7%, n=447, $p=0.002$), compared to those who did not have a diagnostic error. The median time from injury to death was significantly less in the diagnostic error group (seven days compared to 17 days, $p < 0.001$). Examples of typical cases with a diagnostic error are presented in the online supplementary material. The number of PAEs and diagnostic errors increased during the study period, but so did the number of all patients with CSIs. The PAEs / diagnostic error ratio in relation to the number of all patients with CSIs increased slightly during the study years (Fig 2). The PAEs (n = 206) were classified into six different categories as presented in Table 3. The most frequent recorded PAE types were related to CSI diagnostics and events related to health care facilities. It is worth noting that 1,297 patients with CSIs died on the day of injury, and 107 (8.2%) of them died at a medical facility. It is possible that some of these 1,297 patients experienced PAEs that are not included in our study.

Insert Figure 2 about here

Insert Table 2 about here

Insert Supplement about here

Insert Table 3 about here

Discussion

Principal Findings

In this nationwide, retrospective, death certificate-based study, we found preventable diagnostic errors in 13.8% of those who survived at least until the next day after a CSI. The patients who experienced diagnostic errors were significantly older, and the mechanism of injury was more often a fall compared to patients who did not experience diagnostic errors. Diagnostic errors were associated with significantly less time from injury to death. Contrary to our hypothesis, the incidence of diagnostic errors did not decrease during the 24–year study period from 1987 to 2010 despite advancements in radiological services and increased availability of CT for CSI diagnostics. At least four factors might have contributed to this. First, the number of elderly and presumably more frail people (who are prone to AEs) in our society has increased. Patients included in this study were older toward the end of the study period (see data presented in our previous article).(11) Second, a considerable number of the diagnostic errors resulted from the lack of suspicion of CSI (throughout the study period), thus not even conventional roentgenograms of the neck were performed (online supplement, case examples 1,4,6,8, and 9). Therefore, greater availability of CT over time could not influence the error rate of these and similar patients. Third, many death reports from the late 80's and early 90's were briefer and less informative than the more recent ones, which made it impossible to draw solid conclusions on possible AEs. Therefore, the number of cases in the early years of the study may be artificially lower. Fourth, in XXX the overall rate of medicolegal autopsies has increased during the study period,(46) making it more likely that errors would be detected over time. We suspect that diagnostic accuracy has likely improved over time, but this is not reflected in this death certificate based study because medicolegal autopsy was performed on 82.8% of all patients with CSIs who died after the day of injury.

We suggest that diagnostic errors are a substantial cause of preventable harm in primary and in secondary care of patients with CSIs. We found a high frequency of diagnostic errors following ground-level falls among older individuals, whose physical frailty may increase the risk of these relatively low-impact injuries. It has been previously shown that evidence-based clinical decision rules for CSI, applied to elderly patients, have failed to predict injury in some cases.(47, 48) In addition to the physical frailty associated with senescence, older patients might provide vague complaints, while younger patients might be more explicit about describing neck pain and/or neurological symptoms. However, the incidence of diagnostic errors in younger populations might also be higher than presented in this death certificate based study, but because of their better general health status, the errors (leading to tetraparesis, for example) are more rarely fatal and therefore not shown in this study. Diagnostic errors are important AE types because they are in most cases preventable and their consequences are often severe.

The number of other PAEs, separate from diagnostic errors, was also rather high. Events in health care facilities (including falling in nursing homes) were the second largest category of PAEs after diagnostic errors. Improvement of personnel resources in some health care facilities, such as under-resourced nursing homes, might reduce the rate of these events. Fall prevention in general is crucial to reduce the number of CSIs.

Strengths and Weaknesses of the Study

To the best of our knowledge, this is the first death certificate-based nationwide study to examine the number of diagnostic errors in patients with CSIs. A medicolegal autopsy was performed on 92.2% of patients who experienced a diagnostic error and on 82.8% of all patients with CSIs who died after the day of injury. The XXX official cause-of-death statistics are, in practice, 100% complete and the autopsy rates in XXX are considerably higher than in many other western countries, which strengthen our results.(45) In addition, all residents in XXX are covered by public health care which means that no patients are denied medical care (including for example CT imaging) based on socio-economic status, age, or other reasons. Total health spending accounted for 9.3% of the GDP in 2012, which is slightly lower than the average in Organization for Economic Cooperation and Development countries. The quality of healthcare in XXX is generally considered good.(49)

However, this study has several limitations. First, the study's data extraction was restricted to death certificates only. Information was sometimes limited for drawing a solid conclusion about possible adverse events. Because we did not have access to the full autopsy reports, it is possible that we are underestimating PAEs. Second, the identification and classification of PAEs was susceptible to subjective considerations from the authors (XXXX and XXXX), and as such could have introduced bias. Both authors have considerable experience in diagnosing and treating patients with CSIs, but inter-rater reliability was not measured. One could, for example, argue about the possible preventability of an elderly patient falling in a nursing home. In this study, we focused on diagnostic errors because the available data from death certificates was often limited for drawing conclusions about other kinds of PAEs. In contrast, the identification and classification of diagnostic errors was straightforward in most cases. It should be noted that the PAEs or diagnostic errors did not necessarily influence the death of individual patients, even though the median time between injury and death was significantly less for those with diagnostic errors.

Strengths and Weaknesses in Relation to Other Studies

During the 24-year observation period, the number of CSI-related diagnostic errors was clearly greater than in previous more general studies conducted in hospital settings.(35, 36, 38, 50) However, our findings are in line with prior autopsy studies showing that major diagnostic discrepancies are commonly identified in more than 10% of cases.(51-54)

In the history of medicine, autopsy has been described as the most powerful tool and the "gold standard" for detecting diagnostic errors.(55, 56) It is shown that a substantial proportion of fatal spinal cord injuries are without radiographic abnormalities at CT.(57) Nevertheless, it is essential to understand that autopsy studies only provide the error rate in patients who die. Because the diagnostic error rate is almost certainly lower among patients who are still alive, error rates derived solely from autopsy data are inflated. For example, whereas autopsy studies suggest that fatal pulmonary embolism is misdiagnosed approximately 55% of the time, the misdiagnosis rate for all cases of pulmonary embolism is only 4%.(52, 58) Feedback from autopsies is a helpful component of physician training, but the declining number of autopsies performed in many countries limits this opportunity.

We analyzed diagnostic errors from only a subpopulation that died after the day of injury (93.8% of those died in a medical facility). If the entire population of people who died following CSIs (n = 2,041) had been analyzed, the percentage of diagnostic errors likely would have been lower, given that over 90% of patients who died on the day of injury died outside of hospitals and therefore were less likely to have diagnostic errors.

Unanswered Questions and Future Research

Re-examining the death certificates of the 1,297 patients with CSIs who died during the day of injury would yield more data on the possible PAEs that happened in the field by first aid personnel. That might provide us with the number of PAEs in the total population who died and more data about the PAEs by first aid personnel. We believe that the high number of missed CSIs in this study is not a country specific finding considering the generally good XXXX healthcare system. This could be determined by performing similar death certificate based studies in other countries. Further prospective studies are also needed to evaluate the signs and symptoms of elderly patients with CSIs. In a retrospective setting, global trigger tools or other computer-assisted chart review methods might be helpful for identifying risk factors for diagnostic errors in patients with CSIs.(59)

Conclusions

Cervical spine injury diagnostics remain difficult despite improved radiological services. Frail elderly people with diminished physical capacity represent the majority of patients who experienced diagnostic errors in this population of patients with CSIs who died. In our analysis, preventable adverse events and diagnostic errors were most commonly associated with ground-level falls. Although diagnostic errors cannot be eliminated, adherence to evidence-based guidelines and acknowledging their limitations especially among elderly patients might reduce the frequency of some of these events and errors.(47, 48, 60, 61) Continuing medical education and quality improvement initiatives might also reduce adverse events and diagnostic errors.

"What this paper adds" box

Section 1: Cervical spine injury (CSI) diagnostics have improved with advancements in radiological services. However, this death-certificate based nationwide study of the incidence and risk factors for diagnostic errors among patients who die following a CSI indicates that the diagnostic error rate is not declining. Hence, CSI diagnostics remain problematic and diagnostic errors may lead to excess harm for patients.

Section 2: The injury mechanism of patients who were identified as experiencing preventable diagnostic errors was most often a ground-level fall. We emphasize that special consideration in cervical spine evaluation should be given to elderly patients who sustain a low energy trauma.

Footnotes

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Competing interests

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: no support from any organization for the submitted work; no financial relationships with any organizations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Transparency declaration

The lead author affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

Data sharing

No additional data available.

Ethical approval

This study was approved by the Ethics Committee of XXXX Hospital District, XXXX, XXXX (reference number: R12215)

Contributors

TN and TT conceived the idea for the study. JÖ, AR, and TL also made important contributions to the concept and design of the study. TT and TN had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. TT is the guarantor. All authors contributed to the analysis and interpretation of the data. TT drafted the initial manuscript and all authors contributed to the critical revision of the manuscript.

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Figure 1. Flowchart of the patients with CSIs in the study

CSI = Cervical Spine Injury; PAE = Preventable Adverse Event

Figure 2. The annual percentages of patients with preventable adverse events (PAE) and diagnostic errors for all patients with CSIs who died after the day of injury (n = 744)

Table 1. Comparison of characteristics of patients who died on the day of injury and patients who died after the day of injury.

	Patients who died on the day of injury n=1,297 (63.5%)		Patients who died after the day of injury n=744 (36.5%)		
	n	%	n	%	p
Gender,					0.013
Female	376	29	178	23.9	
Male	921	71	566	76.1	
Age at death, years, median (95% CI)	55.0 (50.7-53.2)		75.7 (71.3-73.6)		<0.001
Alcohol mentioned	482	37.2	126	16.9	<0.001
Drugs mentioned	59	4.5	4	0.5	<0.001
CSI as main cause of death	1,243	95.8	604	81.2	<0.001
C0-C2 injury	598	46.1	241	32.4	<0.001
Spinal cord injury	1,182	91.1	512	68.8	<0.001
Cause of injury					<0.001
Fall	383	29.5	536	72.0	
Traffic accident	670	51.7	158	21.2	
Suicide	173	13.3	5	0.7	
Other traumatic or unspecified	71	5.5	45	6.0	
Place of death					<0.001
Medical facility	107	8.2	698	93.8	
Home or residence	261	20.1	29	3.9	
Other	907	69.6	14	1.9	
Abroad	22	1.7	3	0.4	
Death certification					<0.001
No autopsy	1	0,1	120	16.1	
Hospital autopsy	0	0	5	0.7	
Medicoloegal autopsy	1,291	99.5	616	82.8	
Other	5	0.4	3	0.4	

Table 2. Characteristics of patients with CSIs who died after the day of injury stratified by whether or not the patients experienced a diagnostic error.

	Diagnostic error n=103		No diagnostic error n=641			Total n=744	
	n	%	n	%	p	n	%
Gender					0.873		
Female	24	23.3	154	24		178	23.9
Male	79	76.7	487	76		566	76.1
Age at death, years, median (95% CI)	79.4 (75.9-80.1)		74.9 (70.2-72.9)		0.001	75.7 (71.3-73.6)	
Alcohol mentioned	20	19.4	106	16.5	0.469	126	16.9
Drugs mentioned	0	0	4	0.6	0.421	4	0.5
CSI as main cause of death	79	76.7	525	81.9	0.21	604	81.2
C0-C2 injury	28	27.2	213	33.2	0.224	241	32.4
Spinal cord injury	66	64.1	446	69.6	0.263	512	68.8
Cause of injury					0.002		
Fall	89	86.4	447	69.7		536	72
Traffic accident	8	7.8	150	23.4		158	21.2
Suicide	0	0	5	0.8		5	0.7
Other traumatic or unspecified	6	5.8	39	6.1		45	6
Place of death					0.647		
Medical facility	95	92.2	603	94.1		698	93.8
Home or residence	6	5.8	23	3.6		29	3.9
Other	2	1.9	12	1.9		14	1.9
Abroad	0	0	3	0.5		3	0.4
Time since injury to death, Median, Days (min-max)	7 (1-1,442)		17 (1-13,849)		<0.001	16 (1-13,849)	
Time since injury to death					0.005		
1-7 days	49	47.6	198	30.9		247	33.2
8-30 days	27	26.2	183	28.5		210	28.2
31 days-1 year	19	18.4	206	32.1		225	30.2
> year	2	1.9	28	4.4		30	4.0
Data missing	6	5.8	26	4.1		32	4.3
Death certification					0.023		
No autopsy	7	6.8	113	17.6		120	16.1
Hospital autopsy	0	0	5	0.8		5	0.7
Medicolegal autopsy	95	92.2	521	81.3		616	82.8
Other	1	1	2	0.3		3	0.4
Place of diagnostic error							
Primary health care	41	39.8	-	-		41	5.5
Spezialized health care	57	55.3	-	-		57	7.7
Undetermined	5	4.9	-	-		5	0.7

Table 3. Preventable adverse events (n=206) stratified into six categories.

Preventable adverse event category	n	%
Total	206	100.0
Diagnostic errors	103	50.0
CSI diagnosis missed during lifetime	59	28.6
CSI diagnosis delayed	41	20.0
Diagnostic other	3	1.5
Health care facility related events (fall at the ward, fall from bed, wrong place of treatment, or fell from wheelchair)	36	17.5
Treatment related events (wrong treatment, CSI operation not performed, supine skull traction for elderly, medication related, related to halo for stabilizing head and neck, iatrogenic aspiration of blood, too early extubation, or post-operative bleeding related to anticoagulant treatment)	31	15.0
Secondary complication (pressure ulcer, pulmonary embolism, or preventable aspiration)	20	9.7
Surgical treatment related events (peri-operative death, surgical hardware error, suboptimal operation, or post-operative infection/hematoma)	12	5.8
Other (post-surgery brain infarction, removal of collar by patient, or NORO-diarrhea)	3	1.5

1 Figure 1.

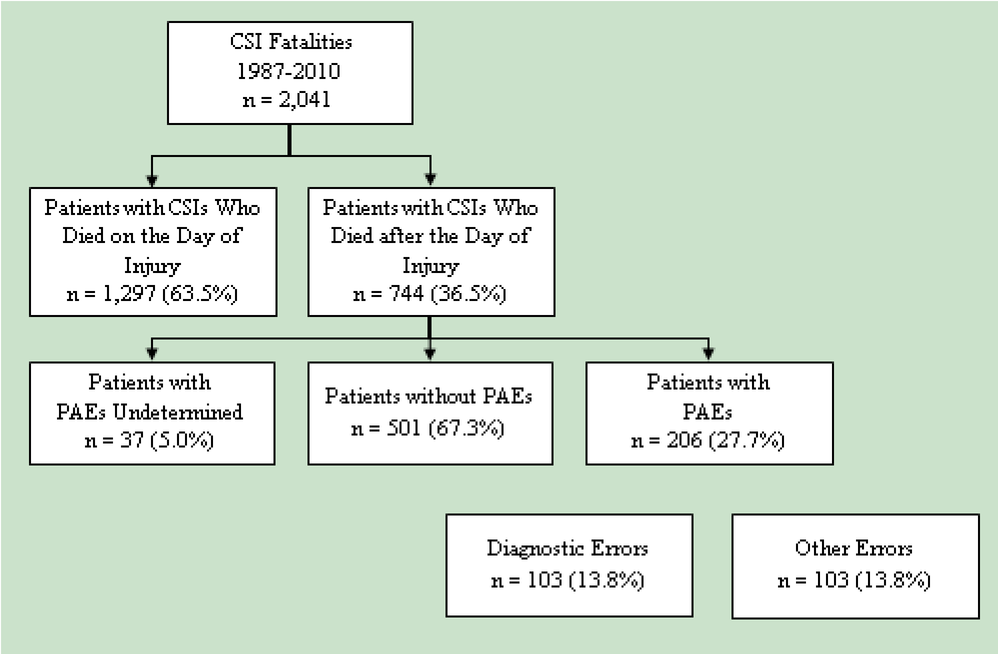

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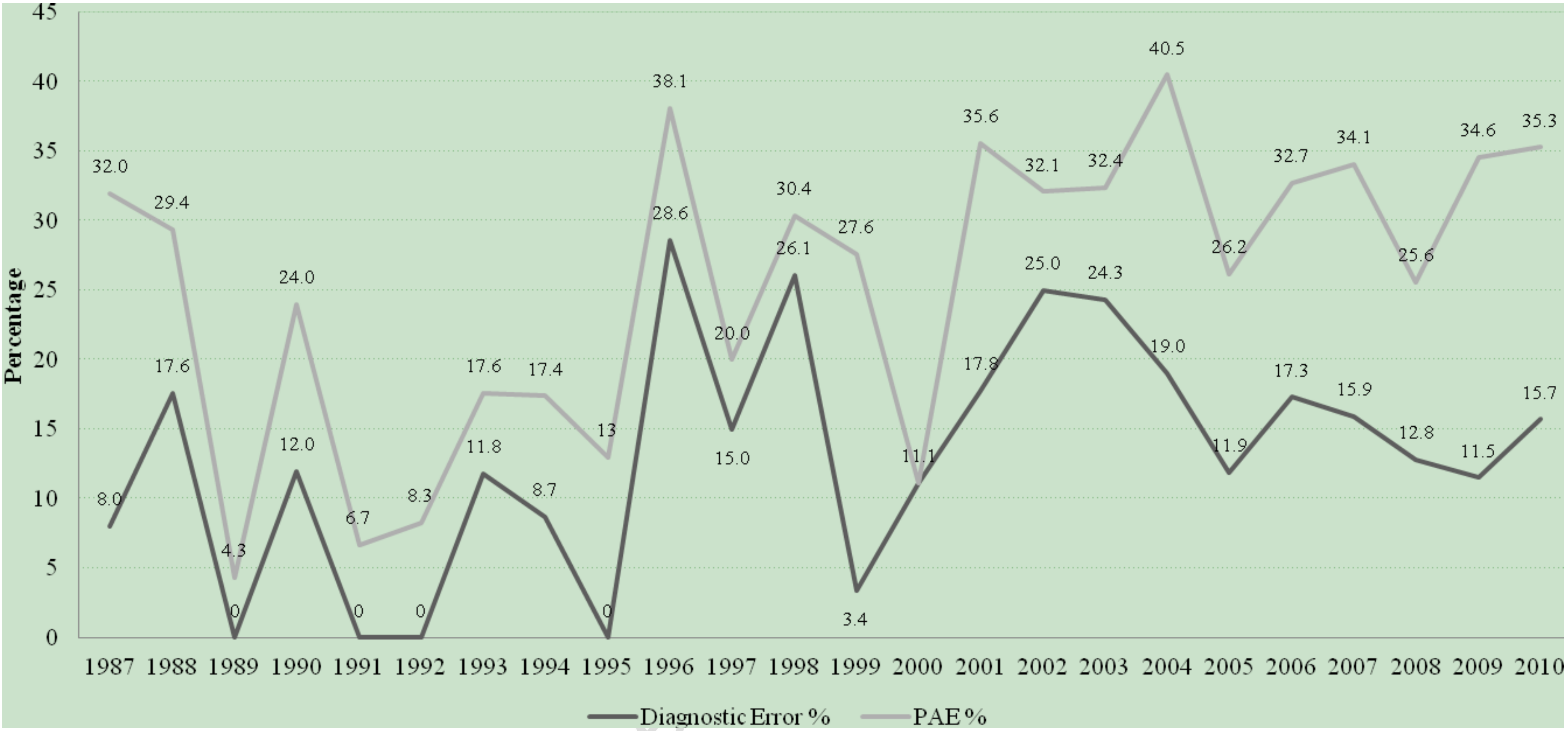
Figure 2.



Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Diagnostic error (n)	2	3	0	3	0	0	2	2	0	6	3	6	1	3	8	7	9	8	5	9	7	5	6	8
PAE (n)	8	5	1	6	1	2	3	4	3	8	4	7	8	3	16	9	12	17	11	17	15	10	18	18
All patients (n)	25	17	23	25	15	24	17	23	23	21	20	23	29	27	45	28	37	42	42	52	44	39	52	51

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ORIGINAL ARTICLE - BRAIN INJURY

Head injuries and the risk of concurrent cervical spine fractures

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Abstract
Background Cervical spine injuries of variable severity are common among patients with an acute traumatic brain injury (TBI). We hypothesised that TBI patients with positive head computed tomography (CT) scans would have a significantly higher risk of having an associated cervical spine fracture compared to patients with negative head CT scans.
Method This widely generalisable retrospective sample was derived from 3,023 consecutive patients, who, due to an acute head injury (HI), underwent head CT at the Emergency Department of Tampere University Hospital (August 2010–July 2012). Medical records were reviewed to identify the individuals whose cervical spine was CT-imaged within 1 week after primary head CT due to a clinical suspicion of a cervical spine injury (CSI) ($n = 1{,}091$).
Results Of the whole cranio-cervically CT-imaged sample ($n = 1{,}091$), 24.7% ($n = 269$) had an acute CT-positive TBI. Car accidents 22.4% ($n = 244$) and falls 47.8% ($n = 521$) were the most frequent injury mechanisms. On cervical CT, any type of fracture was found in 6.6% ($n = 72$) and dislocation and/or subluxation in 2.8% ($n = 31$) of the patients. The patients with acute traumatic intracranial lesions had significantly ($p = 0.04$; OR = 1.689) more cervical spine fractures (9.3%, $n = 25$) compared to head CT-negative patients (5.7%, $n = 47$). On an individual cervical column level, head CT positivity was especially related to C6 fractures ($p = 0.031$, OR = 2.769). Patients with cervical spine fractures ($n = 72$) had altogether 101 fractured vertebrae, which were most often C2 (22.8, $n = 23$), C7 (19.8%, $n = 20$) and C6 (16.8%, $n = 17$).
Conclusions Head trauma patients with acute intracranial lesions on CT have a higher risk for cervical spine fractures in comparison to patients with a CT-negative head injury. Although statistically significant, the difference in fracture rate was small. However, based on these results, we suggest that cervical spine fractures should be acknowledged when treating CT-positive TBIs.

Keywords Brain injuries · Computed tomography · Head injury · Spinal injuries · Cervical spine fractures

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Introduction

The evaluation of the cervical spine among emergency trauma patients is challenging and is frequently complicated by extracervical injuries and other comorbid conditions [1]. Undetected cervical spine injuries (CSIs) may have catastrophic consequences, leading to serious neurological impairment or even death [22].

According to the National Emergency X-Radiography Utilization Study (NEXUS), a clinically significant CSI can be excluded without imaging if none of the following five criteria are fulfilled: (1) focal neurological deficits, (2) midline spinal tenderness, (3) altered level of consciousness, (4) intoxication or (5) distracting injury [11]. However, in many clinical settings, these criteria are not operable. Patients with head injury (HI) and/or traumatic brain injury (TBI) comprise the largest group of patients seen in emergency departments, where clinical examination alone is not sufficient to rule out CSI. The rule of thumb is that all patients with HIs should be treated as if a concomitant CSI is present until proven otherwise. In multitrauma patients, a whole-body computed tomography (CT) from head to pelvis should be obtained on arrival at the emergency department (ED) [3, 9, 16, 21]. However, patients with less serious or isolated HIs comprise the largest group of patients when it comes to the dilemma of cervical spine clearance. It remains rather unclear which HI patients should undergo routine cervical spine CT imaging. Excessive and liberal use of CT raises direct medical costs and increases the risk of radiation-induced malignancies [17].

The incidence of CSI in HI patients has been reported to range from 4 to 8% [3, 4, 10, 18, 20, 26]. To what extent head trauma severity is associated with concomitant CSIs is controversial and depends largely upon the study methods and population studied. Vahldiek et al. [25] did not find an association between positive head CTs and CSIs in their study that comprised only low-energy injuries. Several studies have included only CT-positive or unconscious HI patients [2, 8, 12, 23, 24]. Moreover, many studies have been large multicentre registry or databank studies in which the details of CSIs and HIs have been limited [5, 8, 20]. In general, several factors in trauma patients have been reported to associate with CSI; for example, age, lowered Glasgow Coma Scale score (GCS), injury mechanism, facial fracture and hypotension [8, 12, 20, 24]. Table 1 summarises the central original publications related to the topic and their key findings.

We hypothesised that HI patients with positive head CT scans would have a significantly higher risk of having a cervical spine fracture than HI patients with negative head CT scans. Due to the suboptimal accuracy of CT in detecting vertebral ligament injuries, our study is focused on fractures.

Materials and methods

Study design and setting

This study is a part of the Tampere Traumatic Head and Brain Injury Study. The patient sample in the registry includes all consecutive patients ($n = 3{,}023$) with HI who underwent head CT at the Tampere University Hospital's ED between August 2010 and July 2012. The patients were prospectively enrolled from the ED and the data were retrospectively recorded. In the study, the minimum diagnostic criteria for TBI were based on the WHO Neurotrauma Task Force recommendation [13]. Referral criteria for acute head CT were based on the former Scandinavian guidelines for initial management of minimal, mild and moderate head injuries [14]. Ethics approval (code, R10027) for the study was obtained from the ethical committee of the Pirkanmaa Hospital District in Tampere, Finland.

Clinical data

Data collected from the registry included subject- and injury-related data, clinical information from the ED, and data on neurosurgical interventions. Also, the mechanisms of injury and time intervals (injury—ED admission—head CT—ED discharge) were recorded. Destination after the ED was categorised into four groups: home, hospital ward, local health centre or death. In retrospect, the medical records of all these patients ($n = 3{,}023$) were carefully reviewed to select those individuals whose cervical spine was CT-imaged due to a clinical suspicion of a CSI within 1 week after primary head CT. Cervical CT was performed primarily according to the NEXUS recommendations [11]. On arrival, multitrauma patients underwent whole-body CT (comprising cervical spine) according to international recommendations [3, 9, 16, 21]. A total of 1,091 (36.1%) cervical spine CT-imaged patients were identified and included into the current study. The majority of the patients (96.5%, $n = 1{,}053$) were cervically CT-imaged within 24 h after primary head CT and the rest in 1–4 days' time. Of the CSI patients, the presence of possible spinal cord injury and radiculopathy, as well as the American Spinal Injury Association (ASIA) scores, were recorded [15]. Medical records from a period of 1 year post-injury were reviewed to collect information on possible cervical spine surgery due to the index injury.

Imaging data

In the ED, an emergency non-contrast head CT scan was performed as per Scandinavian guidelines for all patients, using a 64-row CT scanner (Lightspeed VCT; GE, Wisconsin, USA) [14]. In a non-on-call setting, all head CT scans were analysed and systematically coded by two neuroradiologists using a structured data collection form. Acute traumatic intracranial lesions included subdural haematoma and effusion (SDH), epidural haematoma and effusion (EDH), diffuse axonal injury (DAI) lesions, oedema, compression of the cerebrospinal fluid spaces, midline shift, contusions, pneumocephalus, skull fracture and traumatic subarachnoid haemorrhage.

Cervical CT imaging was performed with the same scanner as for the head CTs. CSI was defined as a fracture or

Table 1 List of relevant publications on association of head injury and cervical spine injury

Publication	Study type	Study population	Key findings
Bayless et al. [2]	Single centre, retrospective	228 significant blunt head trauma patients	Only 1.7% of the patients with a significant blunt head trauma had a CSI.
Fujii et al. [5]	National trauma databank	550,313 trauma cases	Incidence of CSI in TBI patients was 8.6%. CSI incidence was significantly higher among TBI patients than among other trauma patients.
Gbaanador et al. [6]	Trauma centre, retrospective	406 patients with HI	CSI occurred in only 1.2% of HI cases. Acute cervical radiography was not efficacious and should not be routinely used in the emergency management of head trauma.
Hasler et al. [8]	Multicentre trauma registry	250,584 major trauma patients	Incidence of CSI in all trauma patients was 3.5%. Patients with lowered GCS or systolic blood pressure, severe facial fractures, dangerous injury mechanism, male gender and/or \ age ≥35 years have an increased risk for CSI. HI was not an independent predictor of CSI.
Hills et al. [10][a]	Single centre	8,285 blunt trauma patients	CSI occurred in 4.5% of HI patients. Patients with clinically significant head injury were at greater risk for CSI. Patients with a GCS ≤ 8 were at even greater risk (7.8%).
Holly et al. [12]	2 centres, retrospective	447 consecutive moderate-severe head trauma patients	Incidence of CSI in head trauma patients was 5.4%. GCS ≤ 8 or motor vehicle accident were risk factors for CSI.
Michael et al. [18]	Single centre, retrospective	359 patients with HI and 92 patients with CSI	CSI occurred in 6% of head injured patients. Coincidence of head injury and CSI in comatose patients was estimated 2.4%. All seriously head injured patients should be treated as having concomitant CSI until proven otherwise.
Milby et al. [19]	Review article	281,864 trauma patients	CSI occurred in 3.7% of all trauma patients and in 7.7% of unevaluable patients (distracting painful injury, intoxication or concomitant HI).
Mulligan et al. [20]	Databank	1.3 million trauma patients	CSI occurred in 7.0% of head injuries. An effective identification protocol for CSI in case of HI is proposed.
Soicher et al. [23]	Single centre, prospective	260 patients from falls or traffic accidents with a significant HI	CSI occurred in 3.5% of significant HI patients. No association between severity of HI and the incidence of CSI.
Tian et al. [24]	Single centre, prospective	1,026 comatose TBI patients	Incidence of CSI in comatose TBI patients was 6.9%. Patients with a low GCS, motorcycle accident as the mechanism of injury and with a skull base fracture had an increased risk for CSI.
Vahldiek et al. [25]	3 centres, retrospective	1,342 minor blunt trauma patients	No association between HI and CSI. Only one patient had combined craniocervical injury.
Williams et al. [26]	Single centre, retrospective	5,021 trauma patients	CSI occurred in 4.8% of HI patients. No significant difference in CSI incidence between HI and non-HI patients. GCS < 14 associated with CSI in HI and non-HI patients.

TBI traumatic brain injury, *CSI* cervical spine injury, *HI* head injury, *GCS* Glasgow Coma Scale

[a] No full text available

subluxation of any of the cervical vertebrae. Whiplash injuries without radiological findings were not included in the analysis. The injured cervical spine level, including occipital condyle (C0) fracture, together with a detailed anatomic description of each vertebra and CT-detectible ligament injury, was recorded systematically by the first author (T.T.). On clinical basis, magnetic resonance imaging was performed on the patients with spinal cord injury, but their results were not analysed in this study.

Statistical analyses

The normality of the variable distributions was tested using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Continuous variables were analysed with the Pearson (normal distribution) and Spearman (skewed distribution) correlation coefficients. Group comparisons were tested with the Student's *t*-test (normal distribution) and the Mann–Whitney *U* test (skewed distribution).

Results

Characteristics of the study sample

The main clinical characteristics of the study sample ($n = 1{,}091$) are presented in Table 2 and CSI-related characteristics in Table 3. For comparison, the characteristics of the patients with positive head CT scans ($n = 269$) are presented parallel with the patients with negative head CT scans ($n = 822$) and the whole study sample ($n = 1{,}091$). Of all the patients ($n = 1{,}091$), 607 (55.6%) fulfilled the clinical criteria for mild TBI, 201 (18.4%) had a moderate or severe TBI and the rest ($n = 283$, 25.9%) had a head trauma without clear signs of TBI. Cervical spinal cord injury was found in 13 (16.9%) of the CSI patients. In one patient, the existence of a possible spinal cord injury remained unknown due to early death caused by a severe TBI.

Cervical CT findings

On cervical CT, CSI was found in 7.1% ($n = 77$) and cervical spine fracture in 6.6% ($n = 72$) of the patients ($n = 1{,}091$). In total, these patients sustained 101 fractured vertebrae. Five patients (0.5%) had a CSI with only a CT-detectible ligament injury. Of the patients with CSI, 31 (40.3%) had dislocations and/or subluxations. The mean dislocation was 3 mm (range, 1–10 mm). The distribution of fractures and dislocations/subluxations is presented in Fig. 1.

Cervical spine fractures in patients with CT-positive versus CT-negative head injuries

Patients with CT-positive acute traumatic intracranial lesions (9.3%, $n = 25$) had significantly more cervical spine fractures (Pearson chi-squared, $p = 0.04$; OR = 1.689, 95% CI = 1.019–2.802) compared with head CT-negative HI patients (5.7%, $n = 47$). Interestingly, patients with positive head CT scans had fewer spinal cord injuries (0.4%, $n = 1$ compared with 1.5%, $n = 12$; statistical comparison not done due to small group sizes). Moreover, positive head CT findings had significant association with C6 vertebra fractures (3.0%, $n = 8$ vs 1.1%, $n = 9$; $p = 0.031$, OR = 2.769, 95% CI = 1.057–7.250), but not with other cervical vertebra fractures (C0-5 and C7) or dislocations/subluxations alone. The distribution of fractures between the upper (C0-C2) and lower (C3-C7) cervical spine did not differ between the two groups. Patients with positive head CT scans (2.2%, $n = 6$) did not have more neurosurgical operations within 1 year post-HI due to cervical spine fractures compared with patients with negative head CT scans (2.8%, $n = 23$; $p = 0.614$).

Risk of cervical spine fractures in relation to neurological picture and mechanism of injury

Patients with cervical spine fractures had more frequently moderate to severe TBIs (22.2%, $n = 16$ vs 18.2%, $n = 185$) but the difference did not reach statistical significance ($p = 0.376$). Also, GCS scores ($p = 0.464$) and number of patients with loss of consciousness (15.3%, $n = 11$ vs 23.7%, $n = 241$, $p = 0.264$) were similar between the groups. However, data on GCS and loss of consciousness were frequently missing (30.6%, $n = 334$; and 42.4%, $n = 463$, respectively).

The gender (males 73.6%, $n = 53$ vs 64.9%, $n = 661$, $p = 0.132$) and mechanism of injury ($p = 0.352$) distributions were not related to cervical spine fractures. Patients with cervical fractures were hospitalised longer (median 96.4 h vs 21.3 h, $p < 0.001$) and underwent more neurosurgical procedures (19.4%, $n = 37$ vs 7.9%, $n = 81$, $p < 0.001$) than the patients without fractures.

Discussion

For clinicians working in the ED setting, detecting patients with a possible CSI is of the utmost importance. Acute HI is one of the most common causes of ED admissions, and the failure to detect CSI, especially in patients with a decreased level of consciousness, can have catastrophic consequences. We found that HI patients with acute intracranial lesions on CT had almost a twofold risk of cervical spine fractures in comparison to CT-negative head trauma patients. In particular, C6 fractures were associated with head CT positivity. Because of the suboptimal accuracy of CT in detecting ligament injuries, we concentrated mainly on fractures in the risk analysis. Compared with prior studies, our results might have superior generalisability as our sample is non-selected and consists of HIs ranging in severity from minimal to severe.

In contrast to our results, there are several reports in the literature stating that HI is not an independent risk factor for CSI [6, 8, 23, 25, 26]. Some of the incoherence between the reported coincidence of TBI and CSI may derive from the differences in the study populations and methods used in different studies. For example, Hasler et al. [8] studied an

Table 2 The characteristics of the study sample stratified into subgroups (head CT-positive patients, head CT-negative patients and whole sample)

Variable	Head CT-positive patients ($n = 269$) Median (95% CI range)		Head CT-negative patients ($n = 822$) Median (95% CI range)		p value	Whole sample ($n = 1{,}091$) Median (95% CI range)	
Age, years	56.1 (53.1–58.2)		42.3 (43.2–46.3)		<0.001	47.2 (46.1–48.8)	
Time intervals, h							
From injury to ED admission	1.7 (8.5–21.4)		1.6 (17.8–33.1)		0.627	1.6 (16.9–28.8)	
From injury to primary head CT	3.0 (9.7–22.6)		2.6 (18.9–34.2)		0.783	2.6 (18.1–30.0)	
From ED admission to primary head CT	0.7 (1.0–1.4)		0.8 (1.0–1.2)		0.168	0.7 (1.0–1.2)	
From primary head CT to hospital discharge	88.1 (140.4–290.4)		15.2 (62.2–101.8)		<0.001	21.9 (91.0–138.8)	
	Head CT-positive patients ($n = 269$)	%	Head CT-negative patients ($n = 822$)	%	p value	Whole sample ($n = 1{,}091$)	%
Gender					<0.001		
Male	202	75.1	512	62.3		714	65.4
Female	67	24.9	310	37.7		377	34.6
Mechanism of injury					<0.001		
Ground-level falls	119	44.2	206	25.1		325	29.8
Falls from a height	48	17.8	148	18.0		196	18.0
Car accidents	21	7.8	223	27.1		244	22.4
Violence-related injuries	15	5.6	49	6.0		64	5.9
Other	15	5.6	42	5.1		57	5.2
Bicycle accidents	20	7.4	49	6.0		69	6.3
Unknown	7	2.6	8	1.0		15	1.4
Sports	3	1.1	24	2.9		27	2.5
Motorcycle accidents	5	1.9	40	4.9		45	4.1
Traffic accidents as a pedestrian	12	4.5	13	1.6		25	2.3
Moped accidents	3	1.1	20	2.4		23	2.1
Location of follow-up treatment					<0.001		
Home	7	2.6	385	46.8		392	35.9
Health centre	28	10.4	85	10.3		113	10.4
Other healthcare facility	1	0.4	19	2.3		20	1.8
Hospital	199	74.0	326	39.7		525	48.1
Death	34	12.6	7	0.9		41	3.8
Alcohol intoxication					0.001		
Yes	94	34.9	209	25.4		303	27.8
No	81	30.1	346	42.1		427	39.1
Unknown	94	34.9	267	32.5		361	33.1
Traumatic head-CT findings	269	100.0	NA	NA		269	24.7
Midline shift	63	23.4	NA	NA		63	5.8
SDH	174	64.7	NA	NA		174	15.9
EDH	15	5.6	NA	NA		15	1.4
Haemocontusion	121	45.0	NA	NA		121	11.1
Contusion	3	1.1	NA	NA		3	0.3
SAH	159	59.1	NA	NA		159	14.6
Skull fracture	109	40.5	NA	NA		109	10.0
DAI	10	3.7	NA	NA		10	0.9
Pneumocephalus	25	9.3	NA	NA		25	2.3
GCS						<0.001	
13–15 points	106	39.4	513	62.4		619	56.7
9–12 points	35	13.0	27	3.3		62	5.7
3–8 points	55	20.4	21	2.6		76	7.0
NA	73	27.1	261	31.8		334	30.6

extensive injury databank and reported that lowered GCS scores predicted CSI, but they found no association between severe HI and CSI. However, Michael et al. [18] found an association between severe HI and CSI in a study conducted in an individual major trauma hospital.

We showed that patients with CT-positive TBI not only have more cervical spine fractures, but, in addition, they have significantly more C6 vertebra fractures. However, the fracture distribution in regard to upper and lower cervical spine did not differ significantly between these two groups (head-CT positive versus negative). Moreover, the incidence of cervical vertebra dislocations/subluxations or neurosurgical operations due to cervical spine fracture was not elevated in the CT-positive TBI group. A neurosurgical operation due to cervical spine fracture was performed on 37.7% ($n = 29$) of the CSI patients during their first year post-injury. None of the patients were treated with a halo-vest, and a few of the patients were treated with either a soft or rigid collar (data not shown).

Table 3 The CSI characteristics of the study sample stratified into subgroups (head CT-positive patients, head CT-negative patients and whole sample)

Variable	Head CT-positive patients ($n = 269$)	%	Head CT-negative patients ($n = 822$)	%	p value	Whole sample ($n = 1,091$)	%
Cervical spine surgery within 1 year post injury	6	2.2	23	2.8	0.614	29	2.7
Cervical spine fracture	25	9.3	47	5.7	0.04	72	6.6
Cervical dislocation/subluxation	8	3.0	23	2.8	0.880	31	2.8
Number of fractured cervical vertebrae	35	13.0	66	8.0	0.014	101	9.3
C0	2	0.7	2	0.2	0.431	4	0.4
C1	5	1.9	5	0.6	0.062	10	0.9
C2 (odontoid)	5	1.9	8	1.0	0.245	13	1.2
C2 (non-odontoid)	5	1.9	11	1.3	0.538	16	1.5
C3	2	0.7	4	0.5	0.621	6	0.5
C4	1	0.4	8	1.0	0.344	9	0.8
C5	4	1.5	8	1.0	0.483	12	1.1
C6	8	3.0	9	1.1	0.031	17	1.6
C7	5	1.9	15	1.8	0.971	20	1.8
Multilevel cervical spine fracture (>1 levels)	9	3.3	13	1.6	0.074	22	2.0
Patients with lower level cervical fracture (C3-C7)	16	5.9	31	3.8	0.127	47	4.3
Patients with upper level cervical fracture (C0-C2)	11	4.1	19	2.3	0.122	30	2.7
Spinal cord injury	1	0.4	12	1.5		13	1.2
ASIA scale					0.490		
A	1	0.4	2	0.2		3	0.3
B	0	0	4	0.5		4	0.4
C	0	0	5	0.6		5	0.5
D	0	0	1	0.1		1	0.1
E or unknown	268	99.6	810	98.5		1078	98.8

In the light of our findings, it can be speculated that although head CT positivity is associated with an increased risk of cervical spine fractures, these fractures are equally severe clinically as measured by the need for surgery. Interestingly, there were also fewer cervical spinal cord injuries in CT-positive TBI patients. This may be due to differences in injury mechanisms. Injury mechanism among patients with a spinal cord injury was remarkably often a simple ground-level fall ($n = 6$, 46.2%), whereas among patients without a spinal cord injury ground-level falls accounted for only 29.6% ($n = 319$) of the cases. Moreover, patients with a spinal cord injury were older (median age, 65.9 vs 47.0 years) than patients without a spinal cord injury. It may be speculated that falling accidents of elderly people are more likely to cause sole cervical spine injuries than CT-positive craniocervical injuries. In a previous study of more than 5,000 trauma patients, Williams et al. [26] found a negative association between TBI and spinal cord injury, which is in line with our findings.

In order to identify risk factors for cervical spine fractures, we compared patients with a fracture to patients who did not have a fracture. In contrast to the majority of the prior literature, we could not find an association between neurological status and fracture risk [8, 12, 24, 26]. However, the amount of missing data on the GCS and loss of consciousness was considerably high and prevents drawing a reliable conclusion in this regard. Injury mechanisms were also somewhat similar between the groups. Ground level falls accounted for about one-third of the cases in both groups and car accidents were more frequent in the fracture group (30.6%, $n = 22$ vs 21.8%, $n = 222$). However, the difference in injury mechanisms was not statistically significant. Nevertheless, it is widely accepted that high-energy injury mechanism increases the risk of cervical spine fractures.

Our results on the distribution of cervical spine fractures were mostly in concordance with the previous reports on trauma patients, although the number of studies focusing on HI patients is scarce [7]. In our study, 30.6% ($n = 22$) of the cervical fracture patients had a multilevel injury. C2 (including odontoid) was the most commonly fractured vertebra consisting 22.8% ($n = 23$) of all ($n = 101$) fractured individual vertebrae. Subaxial fractures ($n = 64$) consisted 63.4% of all fractured vertebrae. Vertebrae C6 ($n = 17$, 16.8%) and C7 ($n = 20$, 19.8%) were the most commonly fractured subaxial vertebrae, whereas C3 was the vertebra least likely to be injured ($n = 6$, 5.9%). Dislocations and subluxations occurred most frequently in C1/C2 ($n = 9$, 29%) and C4/C5 ($n = 7$, 22.6%) levels. In the study by Goldberg et al. [7] on the distribution and patterns of blunt CSIs, the findings were slightly

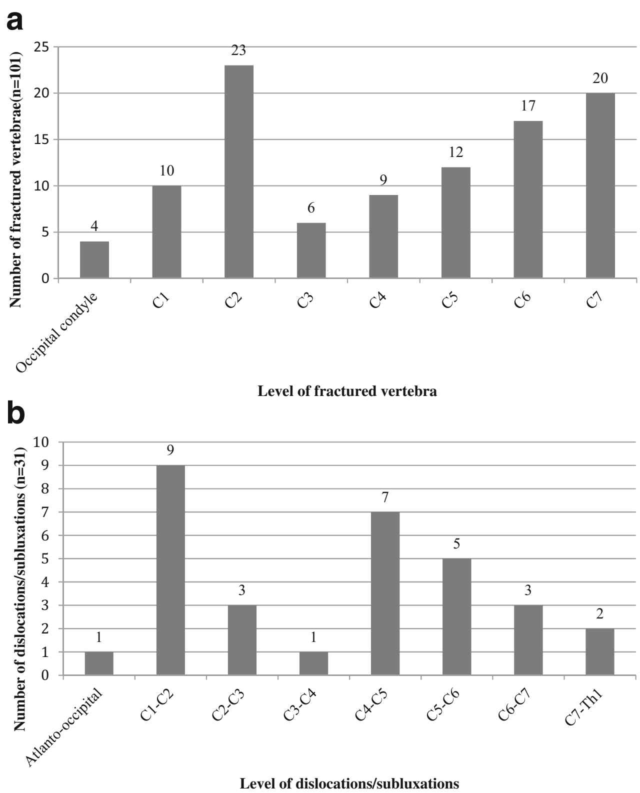

Fig. 1 **a** The distribution of cervical spine fractures. **b** The distribution of cervical spine dislocations/subluxations

different compared to our results. In line with our results, Goldberg et al. reported C2 to be the most commonly fractured cervical vertebra. On the contrary, they found C6 to be the most common site of subaxial fracture, whereas in our series the most common site was C7, followed by C6 fractures. Different study populations (blunt trauma in the study by Goldberg et al. vs HI patients in our study) and different injury coding habits may explain the small differences in the fracture distribution.

Our study represents a large population-based HI sample that is commonly seen in EDs internationally. The sample includes a wide severity spectrum of HIs that were treated at the ED at varying time delays post-injury. Although not unique, our findings support the prior studies on the association between TBI and CSI [3, 10, 12, 18]. However, the main finding of our study (increased risk of cervical spine fractures among head CT-positive TBI patients) must be interpreted with caution given the subtle difference in fracture rate that is only slightly statistically significant ($p = 0.04$). The main limitation of our study is the retrospective nature, and therefore the number of missing data (e.g. GCS and alcohol consumption) is relatively large, which may influence the main conclusions. Secondly, head-CT criteria in minimal, mild and moderate HIs in the ED were based on the Scandinavian guidelines. Apparently, some patients in the sample did not fulfil the Scandinavian CT criteria and were CT-imaged without solid indications. In contrast, possibly some HI patients did not undergo CT imaging although they met the criteria. Thirdly, cervical ligament, and soft tissue injuries may have been missed since patients were not systematically assessed with MRI. However, the main emphasis of this study was on fractures. Most probably, clinically significant CSIs were not missed, since our study included patients whose cervical spine was CT-imaged up to 1 week post-injury and the care of CSIs in the study catchment area is centred to our hospital.

Conclusions

Head trauma patients with acute intracranial lesions on CT have a higher risk for cervical spine fractures in comparison to patients with a CT-negative head injury. However, these fractures did not cause more spinal cord injuries or require more neurosurgical spinal intervention compared to head CT-negative cervical spine fractures. Although statistically significant, the difference in fracture rate is small (9.3% vs 5.7%). Nevertheless, cervical spine fracture should be acknowledged when treating CT-positive TBI patients. CT imaging of the cervical spine in the case of CT-positive TBI should be considered based on these findings.

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Compliance with ethical standards

Conflict of interest All authors certify that they have no affiliations with or involvement in any organisation or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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Ethical approval For this type of study formal consent is not required.

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Comments

Analysing a large 2-year emergency room cohort retrospectively, the authors demonstrate that head injured patients with intracranial lesions on CT harbour an 1.7-fold increased risk of cervical fractures in comparison to CT-negative patients. The conclusion that cervical fractures should be acknowledged when treating CT-positive TBIs can obviously be supported and is kept in mind intuitively in general practice already. The study provides further proof for this concept. However, the risk difference of 9.3% versus 5.7% is too small to make a real difference in the ER. The c-spine clearance rules still have to be applied. Surprisingly, the rate of spinal cord injury was higher in the CT-negative cohort (1.5% vs 0.4%, i.e. 12 patients versus one single patient). It could be speculated that this may be due to central cord syndromes after minor falls in the elderly and is an interesting finding.

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