SPINAL INJURIES
FACTS AND FICTION

JOOST TEN BRINKE

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SPINAL INJURIES
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Promotiecommissie:

Promotor:	prof. dr. J.C. Goslings	AMC-UvA
Copromotor:	dr. T.P. Saltzherr	Haaglanden Medisch Centrum
Overige leden:	prof. dr. O.R.C. Busch	AMC-UvA
	dr. D. van Embden	AMC-UvA
	dr. R.M. Houwert	UMC Utrecht
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Faculteit der Geneeskunde

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CHAPTER 1

General introduction and thesis outline

Introduction

The burden of trauma care on the global healthcare system is considerable. It is estimated that in 2013 973 million people across the globe sustained injuries that required healthcare, and that 4.8 million people died from these trauma-related injuries.[1] Frequently occurring injuries include traumatic spinal injuries of which over 700,000 new cases are reported worldwide each year.[2] Such spinal injuries have the lowest functional outcomes and the lowest return-to-work rates after injury of all major traumas.[3] Given these impacts on society, it is crucial to understand the incidence, characteristics and healthcare demands of spinal injuries and how these parameters develop over time.

Previous studies have shown large geographical variation in the incidence of spinal injuries.[2, 4] For example, the incidence of spinal injuries between developed and developing countries, with higher incidences in developing countries than in developed countries (13.7 versus 8.7 per 100,000 persons).[2] In the Netherlands, the incidence of spinal injuries is far from clear. Epidemiological studies in this country have shown an incidence of osteoporotic spinal fractures in 2008 of 103.6 per 100,000 [5] and an incidence of spinal cord injuries in 2010 of 1.4 per 100,000.[5, 6] However, there is no overview of the incidence, severity and healthcare requirements of all types of spinal injuries in the Netherlands and how this has evolved over time. Such information may offer a rational basis for public healthcare decision-making and resource allocation.

The diagnosis and treatment of patients with suspected spinal fractures is a cumbersome procedure. Healthcare workers in both the pre-hospital and in-hospital setting are required to take rigorous precautionary measures and follow strict protocols to rule out an injury.[7, 8] One of the current pre-hospital precautionary strategies for suspected spinal injuries is spinal motion restriction – commonly known as spinal immobilization. By definition, spinal motion restriction maintains the spine in anatomic alignment and minimizes movement. The reason for precautionary immobilization is the assumption that unstable spinal injuries can deteriorate due to manipulation or movement, potentially resulting in secondary injury to the spinal cord. Current global guidelines state that trauma patients with suspected spinal injuries should be immobilized to reduce the risk of neurological deterioration.[9-12] This treatment procedure has been accepted and implemented in many countries as the standard of care for over fifty years.

Despite this long-standing tradition of spinal immobilization for suspected spinal injuries, the scientific basis for this precautionary measure is poor [13, 14] and its use is becoming controversial. In addition, given that only 2-3% of immobilized adult patients are subsequently diagnosed with a spinal fracture,[15] many patients are immobilized unnecessarily. Spinal immobilization itself can cause severe side effects, including pressure sores, raised intracranial pressure and difficulties in airway management.[13, 16-18] Besides causing discomfort to the patient, immobilization may take up valuable time in a life-threatening situation.[19] While this is justified

when the benefits outweigh the disadvantages, research conducted over the past decade has raised questions regarding these benefits.[13, 14, 20-22]

Within the balance between benefits and harms, the accuracy of the immobilization criteria is critical. These criteria should allow healthcare workers to discriminate between patients who are in need of spinal immobilization and those who are not, thereby avoiding unnecessary immobilization and the associated risks. However, the criteria in the pre-hospital motion restriction protocols currently used by Emergency Medical Services (EMS) vary greatly between countries.[9, 23-28] This indicates a lack of consensus in terms of which immobilization criteria are the most accurate. Identifying the most accurate immobilization criteria and potentially developing new adequate criteria would be a step forward in preventing unnecessary immobilization. Since previous studies have shown that EMS providers can accurately predict injury severity,[29, 30] incorporating their expert judgement into the immobilization criteria in pre-hospital settings could be beneficial. This has not yet been assessed however.

The Dutch EMS use a pre-hospital immobilization protocol that was introduced in 2010 and updated in 2016.[23, 31] This latest protocol dictates that ambulant and alert patients who can independently extract themselves from the trauma scene and who are able to lie down on a vacuum mattress or spinal board should be transported to the hospital with head blocks only. While this protocol is in accordance with recommendations in the scientific literature,[32, 33] it has led to a discrepancy between the protocol currently used in the pre-hospital setting and that used in the in-hospital setting. The in-hospital protocol follows the guidance of the Advanced Trauma Life Support (ATLS®) training programme,[34] which recommends full spinal immobilization if a spinal injury is suspected, including rigid collar and spinal board. The discrepancy between the protocols means that patients with a suspected spinal injury presenting at the emergency department (ED) without spinal immobilization can potentially receive two different kinds of treatment, one after the other. However, it is currently unknown how frequently this happens or what the consequences are.

The in-hospital protocol ensures that patients presenting at the ED with a suspected spinal injury are immobilized until physicians have 'cleared' the spine of injury. Clearing the spine usually involves two procedures, one of which is radiologic imaging. The other involves applying protocols which differ between and include those recommended or issued by the ATLS training programme,[35] the National Emergency X-Radiography Utilization Study (NEXUS),[7] and the algorithm defined in the Canadian Cervical Spine (C-spine) Rule.[8] The primary imaging modality in adult patients is computed tomography (CT) of the spine, which has a high sensitivity for detecting spinal injuries.[9]

While decision tools to rule out spinal injuries in adults are extensively tested and validated, evidence of the application of these decision tools in children is lacking.[36] For children with suspected spinal injury based on a clinical decision tool such as the NEXUS criteria, various international trauma guidelines recommend plain radiography of the spine, which has a high sensitivity for detecting spinal injuries.[37, 38] An additional CT scan of the spine is only

indicated for children with a visible fracture on plain radiography, or for children for with clinical suspicion of spinal injuries despite a negative result with plain radiography.[39, 40] In children, plain radiography is preferred because CT carries an increased risk of cancer: the relative risk of developing thyroid cancer due to a CT scan is considered to be 13 to 25% higher than the risk from a plain radiograph.[40-42] Although the guidelines on imaging of the cervical spine in the paediatric population are clear, CT usage in general has increased considerably since its introduction in adults and in children, especially in the ED.[43] Despite this, an overview of the degree of protocol adherence regarding C-spine imaging in the paediatric population is not currently available.

Aim of the thesis

The aim of this thesis is to determine the incidence of spinal injuries in the Netherlands, to evaluate the effectiveness of spinal immobilization procedures, and to document the diagnostic work up of spinal injuries in the paediatric population. In order to meet these objectives, this thesis addresses the following six research questions:

1. What are the incidences of spinal injuries in the Netherlands?
2. Can spinal immobilization be explained historically?
3. How accurately can paramedics predict the presence of a spinal fracture?
4. What is the most accurate and best analysed pre-hospital spinal immobilization protocol for identifying trauma patients with a spinal injury in need of immobilization?
5. What is the impact of secondary in-hospital immobilization?
6. What is the incidence of spinal injury in children and what is the level of protocol adherence regarding imaging of the spine?

These research questions are addressed in Chapters 2-7.

Outline of the thesis

Chapter 2 describes in an epidemiology study the magnitude of spinal injuries in the Netherlands over a 15-year period.

Chapter 3 provides a historical overview of the development and reasoning behind the implementation of pre-hospital spine immobilization.

Chapter 4 focuses on the potential ability of paramedics to predict spinal injuries in a prospective cohort.

Chapter 5 analyses the pre-hospital spinal immobilization protocols in a systematic review to identify the most reliable and accurate protocol in trauma patients with a spinal injury in need of immobilization.

Chapter 6 describes in a retrospective cohort the numbers of patients suspected of spinal injury who do receive secondary in-hospital spinal immobilization at the emergency department.

Chapter 7 deals with protocol adherence regarding the timing and the type of imaging performed in the paediatric population suspected of spinal injury.

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CHAPTER 2

Incidence of spinal fractures in the Netherlands 1997 - 2012

J.G. ten Brinke, T.P. Saltzherr, M.J.M. Panneman , M. Hogervorst, J.C. Goslings

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Abstract

Study objective

To determine time trends of emergency department (ED) visits, hospitalization rates, spinal cord lesions and characteristics of patients with spinal fractures in the Netherlands.

Methods

In an observational database study we used the Dutch Injury Surveillance System to analyse spinal fracture-related ED visits, hospitalization rates and spinal cord lesions between 1997 and 2012.

Results

The total number of ED visits associated with spinal fractures increased from 4,507 in 1997 to 9,690 in 2012 (115% increase). The increase in the total number of fractures occurred in all age groups independently of gender. However, incidence rates increased more strongly with age and were higher in young males and ageing females. The hospitalization rate of diagnosed spinal fractures remained stable between 62 and 67%. The incidence of spinal cord lesions varied between 13.8 and 20.3 per million of the population over a period of 15 years.

Conclusion

Spinal fracture-related ED visits are increasing in the Dutch population, independently of age or gender. The hospitalization rate and the absolute numbers of spinal cord lesions have remained stable over a period of 15 years. These findings are relevant for public health decision-making and resource allocation.

Introduction

Approximately two million patients visit Dutch emergency departments (ED) each year.[1] While only a minority of these patients have a spinal fracture,[2] the consequences can be severe: spinal fractures and associated spinal cord lesions can lead to functional impairment, impaired quality of life, and increased mortality.[3] Although epidemiological studies of osteoporotic and traumatic spinal fractures and spinal cord injuries have been performed,[4, 5] there are no data on healthcare demand followed over a period of time of spinal fractures and associated spinal cord lesions across the entire population.

Previous research has shown great variation among nations in the incidence of traumatic spinal fractures and spinal cord lesions (up to a threefold difference), particularly between developed and developing nations.[6, 7] Most studies have demonstrated a bimodal age distribution where the first peak is found in young adults between 15 and 29 years of age, and a second peak in adults older than 65 years of age.[6] It has been estimated that in the year 2000 1.4 million patients worldwide suffered from an osteoporotic spinal fracture, and these numbers are expected to increase due to the ageing population.[8] In the older Dutch population, spinal fracture-related ED visits and hospitalizations are increasing rapidly.[5] However, the incidence of traumatic and osteoporotic spinal fractures and associated spinal cord lesions in the population followed over a period of time has never been investigated. If all spinal fractures can be characterized over a period of time, this will provide data on the magnitude and healthcare demands of the spinal injury population. Such information may offer a rational basis for public health decision-making and resource allocation. The purpose of this study was to answer the following questions: (1) What are the incidence rates of spinal fracture-associated ED visits, hospitalization rates and spinal cord lesions in the Netherlands during a 15-year period? (2) How are these incidence rates distributed over age groups and gender?

Materials and methods

Study design and setting

In an observational database study, we collected data on the number of ED visits, hospitalization rates and spinal cord lesions related to spinal fractures in the Netherlands. We used the Dutch Injury Surveillance System (LIS).[9] This data covered the years 1997 to 2012. LIS gathers data on intentional and unintentional injuries sustained by visitors to the ED. LIS collects data from 14 hospitals in the Netherlands, resulting in a representative 12% sample of injury-related ED visits. Numbers were extrapolated to national estimates. In each year of the study, the Consumer and Safety Institute (Amsterdam, the Netherlands) calculated an extrapolation factor based on the population of the participating hospitals and the Dutch population in that year. The database makes it possible to measure and describe healthcare use during a specific period. A full description of the method has been published by the Consumer and Safety Institute and has been used previously.[5, 10, 11]

Selection of participants

All persons who attended an ED at one of the LIS hospitals were included. A spinal fracture was defined using the ICD 9th revision (1979).[12] In cases where a patient visiting the ED had multiple injuries, the primary diagnosis registered in the LIS was leading in identifying spinal fractures.

Methods and measurements

To calculate the admission rate, discharge was registered as either treated-and-released or treated-and-admitted. Age-specific rates were calculated in three age groups (≤24, 25-54 and ≥55). Numbers were presented for five-year time intervals between 1997 and 2012 (1997, 2002, 2007 and 2012). Incidence rates were expressed per 100,000 or per million person-years.

Outcomes

The primary outcome measures were incidence rates (per 100,000 or per million of the population) and age-specific numbers that were calculated for the three age groups at five-year time intervals.

Analysis

The overall incidence rate for the population was calculated using 'direct standardization' to correct for changes in demographics. Incidence rates were expressed per 100,000 or per million person-years.

Results

In the period from 1997 to 2012, a total of 95,933 ED visitors were diagnosed with a spinal fracture in the Netherlands. As shown in Table 1, the total number of ED visits related to a spinal fracture more than doubled from 4,507 in 1997 to 9,690 in 2012 (115% increase). The overall incidence rate for ED visits due to spinal fractures increased from 27 to 58 per 100,000 persons throughout the study period (see Figure 1). In total, 57,000 patients were admitted to hospital after being diagnosed with a spinal fracture at the ED in the period 1997 to 2012. The absolute number of hospital admissions increased over time from 2826 in 1997 to 5887 in 2012 (see Table 1). However, the hospitalization rate remained stable between 62 and 67% during the study period. In the five-year time intervals between 1997 and 2012, a total of 1052 patients suffered a spinal cord lesion. The absolute number of spinal cord lesions remained constant. The incidence rates varied between 13.8 per million person-years in 1997 and 20.3 in 2007 (see Table 1). Age-specific data are shown in Figure 2. A decrease in spinal fracture-related ED visits was seen from 1997 to 2002 in all age groups. After 2002 an increase was seen in all age groups, with the biggest increase in the group aged 55+ (145%). Incidence rates were higher in young males and ageing females (see Figure 3).

Table 1. ED visits, hospitalization numbers and spinal cord lesions due to spinal fractures in the Netherlands 1997–2012.

	1997	**2002**	**2007**	**2012**
ED visits (no.)	4507	4063	7040	9690
Incidence per 100,000	27	24	42	58
Male %	48 %	50 %	55 %	48 %
Hospitalization (no.)	2826	2479	4675	5887
(%)	63%	62%	67%	62%
Incidence per 100,000	17	15	28	35
Spinal cord lesion (no.)	215	262	332	243
(%)	4.8 %	6.4 %	4.7%	2.5%
Incidence per million	13.8	16.2	20.3	14.5

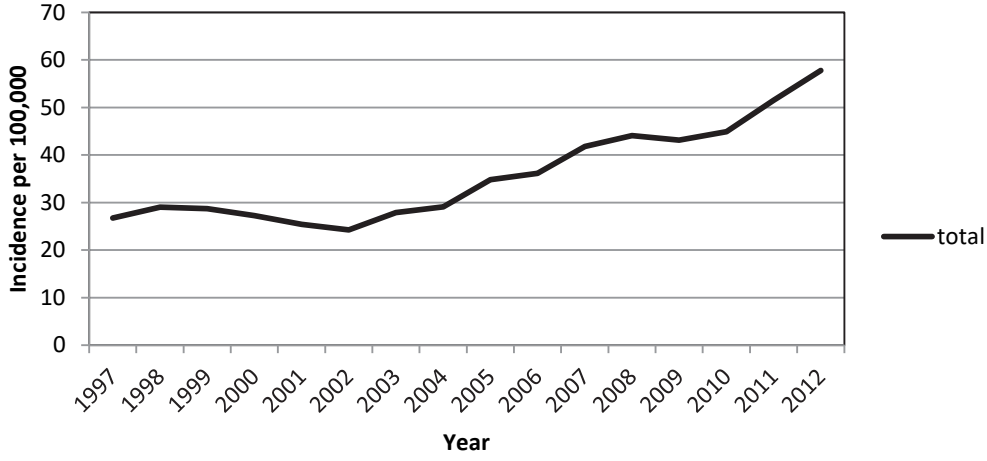

Figure 1. Number of people visiting the ED with a spinal fracture per 100,000 inhabitants per year in the Netherlands (1997–2012).

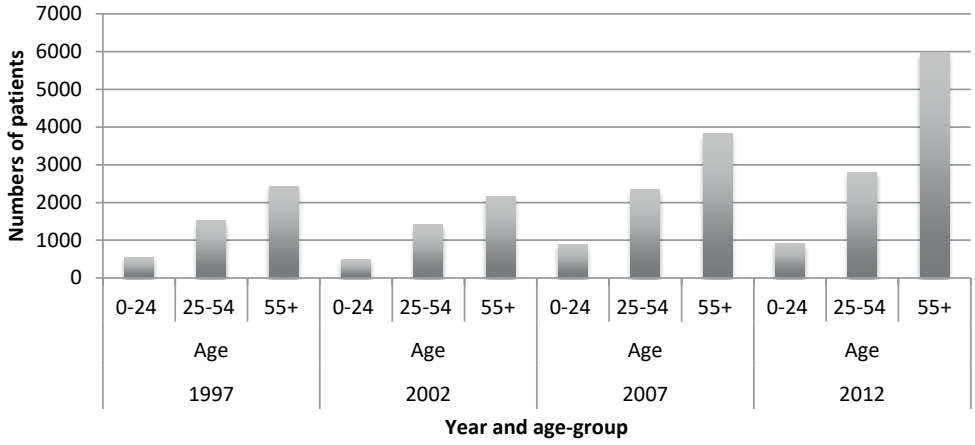

Figure 2. Age-specific numbers of spinal fracture-related ED visits in the Netherlands (1997–2012)

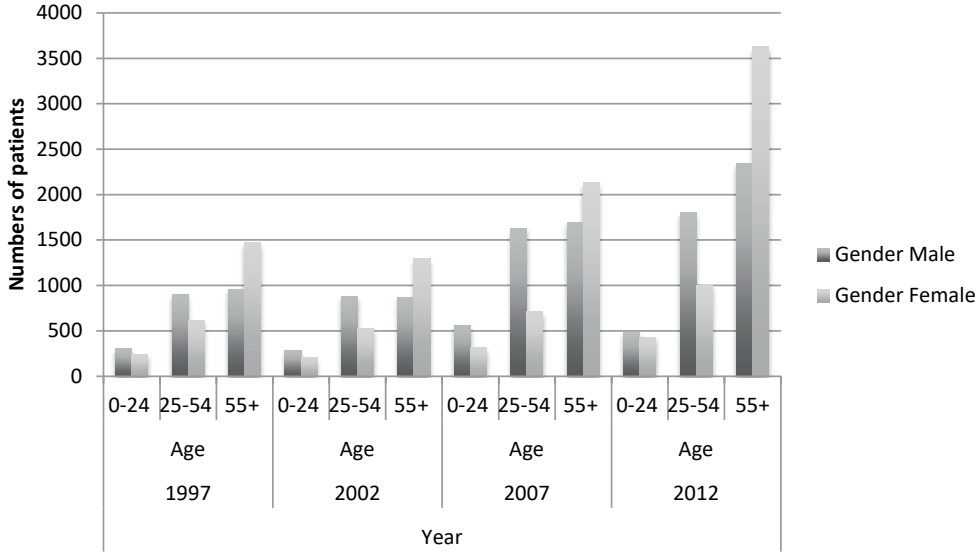

Figure 3. Age- and gender-specific numbers of spinal fracture-related ED visits in the Netherlands (1997–2012)

Discussion

From 1997 to 2012, the absolute number of patients who were diagnosed with a spinal fracture more than doubled. An increase similar in magnitude was also found by Oudshoorn et al (2012)[5] who published a trend analysis of spinal fracture-related ED visits between 1986 and 2008, also using the Dutch Injury Surveillance System. However, they focused on patients aged over 65 years. During the period of time studied they saw an increase of 174% in ED visits due to spinal fractures. This is in line with the results of our study: we found an increase of 145% in the age group 55+. Spinal fracture-related ED visits are expected to increase because of increasing life expectancy, the increasing numbers of older fallers, and the increasing numbers of osteoporotic individuals in the population.[13, 14] In this study, an increase in the incidence of spinal column fractures was seen in all age groups. An explanation for the increase in the total group can be explained by the increased use of computed tomography (CT) scans. This has led to a considerable increase in the numbers of spinal column fractures detected.[15-18]

A systematic review of overall incidence around the world has found great variation among nations in the rate of traumatic spinal column fractures – ranging from 3.6 to 195.[4] patients per million – particularly between developed and developing nations.[6] In 2012, the incidence rate of spinal column fractures in our study was as high as 580 per million of the population. These numbers include osteoporotic spinal fractures. The fact that approximately 90% of spinal fractures are associated with osteoporosis [19] might explain the high incidence rate of spinal column fractures in our study.

Hospital admissions due to spinal fractures increased during the course of our study period from 17 per 100,000 inhabitants in 1997 to 35 in 2012. The Dutch study mentioned above showed an increase in admission rates for the population aged over 65 years from 32.6 per 100,000 inhabitants to 57.5 in the period from 1986 to 20085. In Spain, spinal fractures led to a hospitalization rate of 27.6 per 100,000 inhabitants for individuals aged > 30 years in the year 2002.[20]

The incidence of spinal cord injury found in this study for 2012 is 14.5 per million inhabitants. In other European countries these numbers vary between 10.4 and 29.7 per million inhabitants.[21] In a previous study in the Netherlands the estimated incidence of spinal cord injury was 11.7 per million inhabitants in 2010.[4] Due to local demographic and socioeconomic factors the incidence rate found globally differs.[6, 22] Other factors in estimating the variances in incidence seem to be the differences in methodology and the type of registration used.[6, 21, 23] To compare the incidence of spinal cord across countries includes uniformity in the methods used and clear inclusion criteria.

A limitation of using the LIS database is that it gives us an estimate of our outcome parameters and does not include information about a patient's underlying diagnosis, co-morbidities, and treatments. This hinders the interpretation of causal mechanisms behind the observed trends. Furthermore, the fact that readmissions were not excluded could lead to double registration.

There could therefore be other reasons underlying the increase in spinal fracture-related ED visits observed in our study. Though, no major changes in policy or in the ICD coding system were made that might have affected the increase in spinal fractures in the Netherlands during this period.

Conclusion

Spinal fracture-related ED visits are increasing in the Dutch population, independently of age or gender. The hospitalization rate and the absolute numbers of spinal cord lesions have remained stable over a period of 15 years. These findings are relevant for public health decision-making and resource allocation.

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CHAPTER 3

Prehospital care of spinal injuries: a historical quest for reasoning and evidence

J.G. ten Brinke, S.R. Groen, M. Dehnad, T.P. Saltzherr, M. Hogervorst, J.C. Goslings

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Abstract

Purpose

The practice of prehospital immobilization is coming under increasing scrutiny.Unravelling the historical sequence of prehospital immobilization might shed more light on this matter and help resolve the situation. Main purpose of this review is to provide an overview of the development and reasoning behind the implementation of prehospital spine immobilization.

Methods

An extensive search throughout historical literature and recent evidence based studies was conducted.

Results

The history of treating spinal injuries dates back to prehistoric times. Descriptions of prehospital spinal immobilization are more recent and span two distinct periods. First documentation of its use comes from the early 19th century, when prehospital trauma care was introduced on the battlefields of the Napoleonic wars. The advent of radiology gradually helped to clarify the underlying pathology. In recent decades, adoption of advanced trauma life support has elevated in- hospital trauma-care to an high standard. Practice of in-hospital spine immobilization in case of suspected injury has also been implemented as standard-care in prehospital setting. Evidence for and against prehospital immobilization is equally divided in recent evidence-based studies. In addition, recent studies have shown negative side-effects of immobilisation in penetrating injuries.

Conclusion

Although widely implementation of spinal immobilization to prevent spinal cord injury in both penetrating and blunt injury, it cannot be explained historically. Furthermore, there is no high-level scientific evidence to support or reject immobilisation in blunt injury. Since evidence in favour and against prehospital immobilization is equally divided, the present situation appears to have reached something of a deadlock.

Introduction

The estimated incidence of spinal injury in the United States (US) is 2-6% of all trauma patients.[1] Approximately one-third of patients with spinal injuries are diagnosed with an unstable spinal fracture or injury of the spinal cord.[2-6] When spinal injury is suspected, precautions including spinal immobilization are taken until physicians have 'cleared' the spine of injury. Clearing the spine of injury usually involves radiologic imaging or applying protocols which include those recommended or issued by the Advanced Trauma Life Support (ATLS) training programme, the European Trauma Course (ETC), the National Emergency X-Radiography Utilization Study (NEXUS), as well as the algorithm defined in the Canadian Cervical Spine (C-spine) Rule.[7-10]

Spinal immobilization is indicated based on the assumption that spinal injuries can deteriorate due to manipulation or movement, thereby causing secondary injury to the spinal cord,[11] and it has been accepted and implemented as the standard of care for decades despite the lack of clear evidence to support this practice.[12-16] Although immobilization measures can have adverse effects, they continue to be implemented in modern trauma protocols, with approximately five million patients in the US receiving spinal immobilization every year.[17] Throughout Europe, prehospital emergency medical services are guided by national trauma protocols based on the Prehospital Trauma Life Support (PHTLS) programme and the European approach to trauma care supported by the ETC.[18-21] While the treatment of spinal injuries is known to date back to prehistoric times, the development and rationale behind the implementation of prehospital spine immobilization is only 50 years old.[22, 23]

The main aim of this article is to provide a brief literature review of the history of spinal immobilization and thereby answer the following question: can spinal immobilization be explained historically?

Before prehospital care

The history of treating spinal fractures dates back as far as ancient times. The earliest description dates to 3,000 years B.C. in ancient Egypt: the Edwin Smith Papyrus[24] describes six injuries of the cervical spinal cord, concluding that the best treatment is rest and support (Figure 1). It therefore appears that the Egyptians did not treat spinal cord injuries with surgical intervention.

Later on, in a text from ancient Greece, Hippocrates (460 –377 B.C.) stated that if a fracture was presented with paralysis, no treatment options were possible; he believed that these unfortunate individuals were destined to die. But for deformities of the spine he introduced the extension bench and other methods to reduce such deformities (Figure 2).[25] The methods of Hippocrates were still being taught in Europe in the sixth century A.D.

In the third and fourth century A.D., non-invasive treatment of spinal fractures was described in India and these descriptions included the care of cervical dislocations which involved

reduction, bandages, splints and bed rest. Lower spine injuries were treated by immobilization; patients were placed on a board and tied down with ropes.[26]

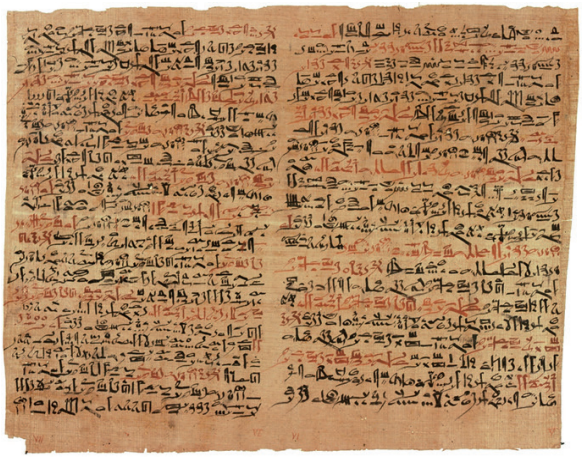

Figure 1. Plates VI & VII of the Edwin Smith Papyrus at the Rare Book Room, New York Academy of Medicine

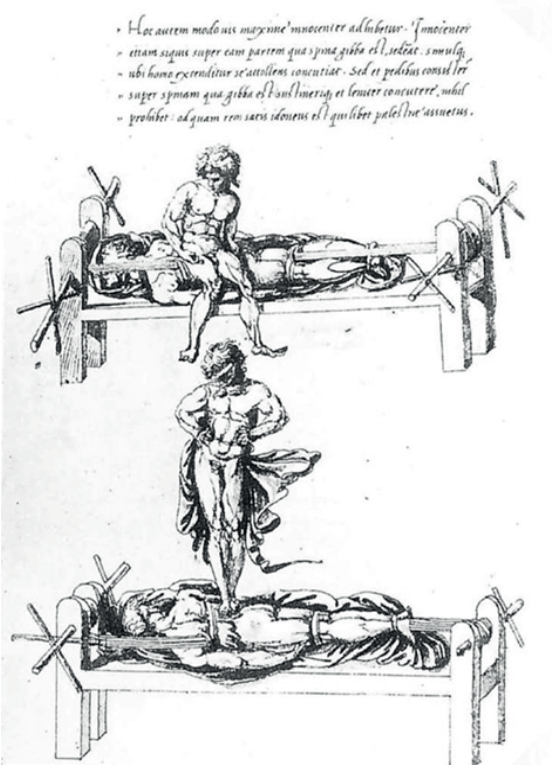

Figure 2. The extension bench with reduction methods on the Hippocratic board, Paris National Library.

Western medicine however remained very primitive, and no recordings of spinal fracture management can be found in sources from the middle ages (700–1400 A.D.).[22] It was not until the Renaissance that European physicians started to publish works on this topic. In his book *Dix Livres de Chirurgie,* the French barber-surgeon Ambroise Paré (1510–1590) mentions repositioning spine fractures by suspending the patient, with the upper body fastened and the feet dangling.[27] Similar accounts can be found in ancient Arab and Chinese literature (Figure 3). Prehospital care for spinal injuries did not exist until the 18th century, during which immobilization was only used as a method of in-hospital treatment.

Figure 3. Treatment of the spinal column Golden Mirror of Medicine, Ciba periodical 1959;94:8.

Prehospital care

Prehospital care for any type of injury, spinal or otherwise – it is thought to have been started by Napoleon's surgeon, Dominique-Jean Larrey (1766–1842). He developed the *ambulances volantes* (flying ambulances) to evacuate casualties from the battlefield during the Italian Campaign of 1797. Flying ambulances were horse-drawn wagons for collecting and carrying the wounded from the battlefield to hospitals (Figure 4). Attending personnel included a doctor, a quartermaster, an officer and infantrymen. Larrey also introduced the first descriptions of triage. Triage derives from the French verb *trier* (meaning 'to pick'), originally describing how early French wool traders sorted wool into various categories according to its quality. The primary purpose of military triage was to prioritize care according to the severity

of injury and the chances of survival. In Larrey's *Memoires de chirurgie militaire et campagnes* he described the immobilization of open fractures, concluding that immobilization facilitated healing. However, spinal injuries are rarely mentioned in Larrey's work [28] and up until the 20th century, prehospital spinal immobilization was not implemented into prehospital care.

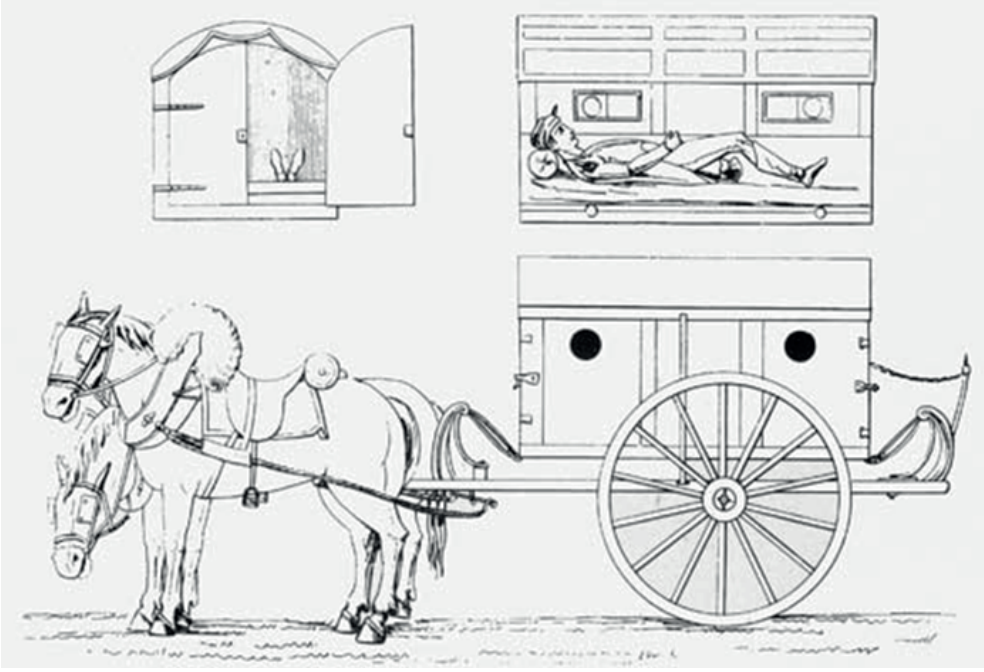

Figure 4. A horse-drawn ambulance designed by Dominique-Jean Larrey, The National Library of Medicine.

Prehospital immobilization

The theory that spinal immobilization prevents secondary neurological deterioration dates from 1966, when Geisler published a retrospective analysis of 958 patients with spinal cord injuries.[29] This article described 29 patients who experienced neurological deterioration after spine injury and concluded that each case of paralysis occurred due to a failure to recognize injury or to protect from the patients from the consequences of their unstable spine.[29] This provided the fundament for the idea that prehospital immobilization could prevent neurological deterioration. Practical implementation of prehospital immobilization is credited to Louis Kossuth, who in 1966 developed a short spine board that stopped at the waist.[30, 31] He later developed a full-body board which was the predecessor of the modern spine board.[32] At the time that Kossuth was popularizing his theory, prehospital care itself was undergoing a significant reorganization.

Until the 1970s, most ambulance services were run by personnel with little training in trauma care.[33] The first basic training in prehospital care for emergency medical technicians (EMTs)

developed from the training of fireman in the 1950s, which was started by Deke Farrington in Chicago and later on in Wisconsin. After publication of Farrington's article 'Death in a Ditch' in the *Bulletin of the American College of Surgeons,* the importance of prehospital care started to be recognized. The subsequent development of a training programme for EMTs encompassed Kossuth's spinal immobilization algorithm.[30]

In 1979, in-hospital trauma care took a giant step forward with the implementation of the ATLS principles.[34] A trauma surgeon affiliated with the ATLS programme, Norman McSwain, subsequently developed a prehospital version of the ATLS programme [35] known as Prehospital Trauma Life Support (PHTLS), and the first PTHLS course was launched in 1983. This programme was based on the theory that spinal immobilization prevents neurological deterioration and reduces risk of secondary injury, and has since been implemented globally.[18] When the need arose for a European approach to trauma care, the ETC was developed – an intensive training module adapted to practice in Europe that provided physicians with guidelines and that took into account international recommendations supported by various training modules.[10]

An evidence-based medicine approach to penetrating trauma

Since the introduction of the trauma care guidelines in the 1980s, spinal immobilization has become standard practice. Nevertheless no randomized controlled trials have ever been published on the effects of spinal immobilization, as highlighted in various review articles.[20, 21, 36, 37] In fact, for penetrating trauma, the results of several studies suggest that spinal immobilization has a negative effect. For example, rigid cervical collars (c-collars) are widely implemented for suspected cervical spine injury (CSI) and four recent observational studies have reported on the effects of applying c-collars for suspected CSI in penetrating trauma.[38-41] In addition, a retrospective chart review conducted by Vanderlan et al. in patients with penetrating cervical trauma reported that, in isolated CSI, cervical spine immobilization using a c-collar was associated with a higher mortality rate when compared with no immobilization (OR 8.82, 95% CI, 1.09-194, p=0.038).[38] In the same study, patients who had undergone cervical spine immobilization had a higher risk of requiring cardiopulmonary resuscitation upon arrival at the emergency department (OR 3.53, 95% CI, 1.06 – 12.95, p=0.037). These results suggest that immobilizing the cervical spine could mask important clinical signs, block access to injury sites, and impair intubation.[38] A large retrospective study by Haut et al. in patients with suspected CSI also reported that cervical spine immobilization was associated with a higher mortality rate when compared with no immobilization (14.7 vs 7.2%, P<0.001), even among patients with lower injury severity scores.[39]

These findings are supported by the results of a retrospective review conducted by Barkana et al. using data from 44 military causalities, which suggest that c-collars can potentially conceal underlying neck injuries, including tracheal deviation, large expending haematoma, and diminished or absent pulse of the carotid artery.[40] Immobilizing the cervical spine is also thought to increase intracranial pressure, thereby impairing the patient's neurological status, as described in a case study by Lemyze et al.[41] All included studies are summarized in table 1 accompanied by the main outcome.

An evidence-based medicine approach to blunt trauma

Although trauma from impaction clearly differs from penetrating trauma, similar results have been described for spinal immobilization following blunt trauma. Data from a large retrospective chart review by Hauswald et al. (table 1) showed no beneficial effect of spinal immobilization on neurological outcome, with the incidence of neurologic injury in the immobilized group almost double those in the non-immobilized group (OR 2.03, 95% CI, 1.03 – 3.99, p=0.04).[42] They suggest that spinal cord injury is primarily the result of the initial impact, and that secondary injuries are not the result of unrestricted movement of the spine.[42] Such secondary injuries can be caused by swelling, formation of free radicals and other chemical mediators.

Table 1. Overview of characteristics and main outcome of included evidence-based studies.

Authors (year)	Study design	Country (study period)	N	Mean age (± *SD*)	Comparison	Main outcome
1. penetrating trauma						
A. Vanderlan et al. (2009)	Retrospective cohort	US (9.3 *yrs*)	188	*NR*	c-collar *vs.* no c-collar	1. Mortality rate OR 8.82 (95% *CI*, 1.09-194, p=0.038) 2. Requiring CPR OR 3.53 (95% *CI*, 1.06-12.95, p=0.037)
B. Haut et al. (2010)	Retrospective cohort	US (3 *yrs*)	45,284	Median 29 *yrs*	c-collar *vs.* no c-collar	Mortality rate 14.7 vs. 7.2% (p<0.001)
C. Barkana et al. (2000)	Case series	Israel (4.5 *yrs*)	44	*NR*	c-collar alone	Potentially concealing underlying neck injury
D. Lemyze et al. (2011)	Cave study	-	1	32	strangulation by hanging alone	Increase of intracranial pressure
2. Blunt trauma						
A. Hauswald et al. (1999)	Retrospective cohort	US, Malaysia (5 *yrs*)	334, 120 (454)	34, 35	C-spine immobilization *vs.* no immobilization	Incidence of neurologic injury OR 2.03 (95% *CI* 1.03-3.99, p=0.04)
B. Lin et al. (2011)	Retrospective cohort	Taiwan (2 *yrs*)	5139	38	c-collar *vs.* no c-collar	No significant correlation of cervical spine injury

Table 1. continues on next page

Continuation of Table 1.

Authors (year)	Study design	Country (study period)	N	Mean age (± *SD*)	Comparison	Main outcome
C. Kreinest et a. (2016)	Review	-	-	-	C-spine immobilization *vs*. no immobilization	Strong associations adverse effects (respiratory compromise, neck and back pain, pressure sores)

Yrs: years, *SD*: standard deviation, *NR*: not reported, *CI*: confidence interval, *vs*: versus.

Similar results were published by Lin et al., who analysed the application of c-collars in victims of lightweight motorcycle accidents with cervical spine injuries.[43] The authors found no significant correlation of cervical spine injury between the patients who had been immobilized and those who had not and they concluded that c-collar application during prehospital care may not always be necessary.[43] In addition, the need for cervical immobilization following motor sport accidents was analysed by Kreinest,et al. who criticizes the application of the c-collar in all trauma patients and developed more selective immobilization criteria.[44]

Despite the assumption that immobilization minimizes spinal movement and thereby reduces risk of secondary injury, there is a lack of high-level evidence that this improves patient outcome. Furthermore, several studies have found strong associations between immobilization and the adverse effects, including respiratory compromise, neck and back pain, and pressure sores, even when immobilization is properly applied.[19, 21, 43, 44, 45, 46] In addition, findings from a recent study by our group suggest that paramedics cannot accurately predict spinal injury in the prehospital setting, and that they fail to identify the subgroup most likely to benefit from cervical spine immobilization.[47]

Given the lack of clear conclusions regarding spinal immobilization, there is a clear need for prospective studies that analyse both its benefits and drawbacks, as others have also indicated.[48, 49]

Discussion

The current standard in prehospital care in trauma patients suspected of spinal injury is to immobilize the spine to prevent secondary spinal cord injury. Although widely implemented, spinal immobilization cannot be explained historically, nor is there any high-level scientific evidence to support or reject it. The first use of prehospital immobilization of the spine was based on the assumption that minimizing spinal movement reduces the risk of secondary injury to the spinal cord and facilitates transportation,[28] although we now know that this is certainly not always the case.[42, 48, 49]

Since the 1970s, the implementation of immobilization in prehospital care has improved through the use of various trauma care algorithms and the application of the principles of the ATLS training programme in the US or as provided in Europa by the ETC.[10, 19, 20, 21, 34] Although these protocols are applied on a large scale, clear evidence to support the rationale for immobilization in prehospital care is lacking [49] and large retrospective studies in patients with penetrating injury have described no beneficial effect on neurologic outcome.[34, 38] Moreover, Hauswald et al. have suggested that the risk of neurologic deterioration in immobilized patients suffering blunt trauma could be twice as high as in non-immobilized patients, thereby casting doubt on immobilization as a preventive measure in both penetrating and blunt trauma.[38] Indeed, an increasing number of studies are now doubting the necessity of applying spinal immobilization and are reporting the associated risks of adverse effects.[38, 42] Spinal immobilization of just the cervical spine using a c-collar in penetrating injuries is known to be associated with an increased risk of respiratory compromise, pain, pressure sores, and increased intracranial pressure.[38, 37] Immobilization is also associated with higher mortality rates as it can mask important clinical signs and underlying injuries, as well as blocking access to injury sites.[34, 35]

Although widely implementation of spinal immobilization to prevent spinal cord injury in both penetrating and blunt injury, it cannot be explained historically. Recent studies have shown negative side-effects of immobilisation in penetrating injuries. Furthermore, there is no high-level scientific evidence to support or reject immobilisation in blunt injury. Paramedics and other health professionals therefore need to be aware of the potential drawbacks of immobilization. Trauma protocols should therefore be critical towards routinely immobilizing trauma patients. Future large prospective trials are needed to provide clear and evidence based criteria in applying spinal immobilization.

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CHAPTER 4

The value of pre-hospital spine fracture presence assessment by paramedics

J.G. ten Brinke, W. klein Gebbink, L. Pallada, T.P. Saltzherr, M. Hogervorst, J.C. Goslings

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Abstract

Background

Current guidelines state that trauma patients at risk of spine injury should have prehospital spine immobilization to reduce the risk of neurological deterioration. Although this approach has been accepted and implemented as a standard for decades, there is little scientific evidence to support it. Furthermore, the potential dangers and sequelae of spine immobilization have been extensively reported. The role of the paramedic in this process has not yet been examined. The aim of this study was to evaluate the ability of prehospital evaluations for the presence of spine fractures made by paramedics.

Methods

All patients who presented with prehospital spine immobilization at our level II trauma center between January 2013 and January 2014 were prospectively included in a database. Prior to the diagnosis, paramedics recorded the probability of a spine fracture after a prehospital examination. These predictions were compared with patient outcomes. The sensitivity, specificity, positive predictive value, and negative predictive value were calculated.

Results

One hundred and thirty-nine patients were included. The positive predictive value was 22%, negative predictive value was 95%, sensitivity was 92%, specificity was 30% and accuracy was 41%.

Conclusions

The results of this study suggest that paramedics cannot accurately predict spinal fractures.

Introduction

Current worldwide guidelines state that trauma patients at risk of spine injury should be immobilized by emergency medical services to reduce the risk of neurological deterioration.[1-5] The reason for these immobilization precautions is the assumption that unstable spinal injuries can deteriorate due to manipulation or movement, thereby causing secondary injury to the spinal cord.[2, 6, 7] This treatment algorithm has been accepted and implemented as the standard of care for decades despite their being little scientific evidence to support this practice.[8-12] More than five million patients in the United States receive spinal immobilization each year.[13] The majority of blunt trauma patients do not have a spine fracture, meaning many patients are unnecessarily immobilized. Spine immobilization can be problematic for both the patient and the paramedic: it can cause pressures sores, compromise respiration, necessitate aspiration after vomiting, raise intracranial pressure and hamper airway management.[14-17] It is also a time-consuming intervention.[17] Development of a more selective immobilization protocol could reduce the number of immobilized patients, thereby decreasing the potential dangers and sequelae associated with unnecessary spine immobilization, often these selective immobilization protocols were initially designed for indications for radiological imaging in emergency rooms and later validated as prehospital immobilization protocol.[18-21]

Although previous research has shown that paramedics can accurately predict injury severity,[22-24] the accuracy of spine fracture prediction has not been investigated so far. The purpose of this study was to answer the following question: how accurate can paramedics predict the presence of a spinal fracture?

Methods

Study design

This was a single institution prospective cohort study. Approval for this study was obtained from the medical ethical committee of Gelre Hospital.

Patients and setting

All patients that presented at the emergency department of our level II trauma center with prehospital immobilization between January 2013 and January 2014 were included in a database.

Before radiologic imaging, paramedics recorded the probability of a spine fracture based on their own evaluation on a data collection form. They were asked to predict any spine fractures by answering ‘Yes’ or ‘No’. The paramedics also recorded the mechanism of injury (MOI). Patients were assessed according to the Advanced Trauma Life Support (ATLS) guidelines [25] and spinal imaging was performed according to Dutch guidelines [26]. The presence of a spine fracture was ruled out if computed tomography scanning was negative or if no clinical symptoms suggesting a spinal injury were detected during the 3-month follow-up period.

Exclusion criteria were the absence of paramedic's prediction and/or lack of appropriate imaging. Patients were stratified based on the prehospital prediction of a spine fracture.

Primary outcome

Sensitivity, specificity, positive predictive value (PPV),negative predictive value (NPV), and accuracy were calculated.

Data analysis

Data was analyzed using SPSS for Windows Version 21.0 (SPSS Inc., Chicago, IL, USA).

Results

A total of 190 patients presented with prehospital spine immobilization and 139 of these patients were included in this study (Figure 1). The baseline characteristics and MOI are presented in Table 1. The prevalence of spine fractures was 17%. Paramedics failed to predict spine fractures in two patients (92% sensitivity, 30% specificity). The PPV was 22% and the NPV was 95%. The accuracy was 41%. The primary outcome and accuracy of this study are presented in Table 2. Twenty-two patients of the 102 where correctly predicted to have spinal fractures by the paramedics. The paramedics failed to identify spine fractures in two patients. The Mechanism of injury in these patients with missed fractures where: fall from height. One of these patients got a Orthesis for pain relief with multiple spinal fractures (Table 3). Thirty-five patients where immobilized by the paramedics due to protocol, however there was no suspicion of a spinal fracture by the paramedics (Table 2).

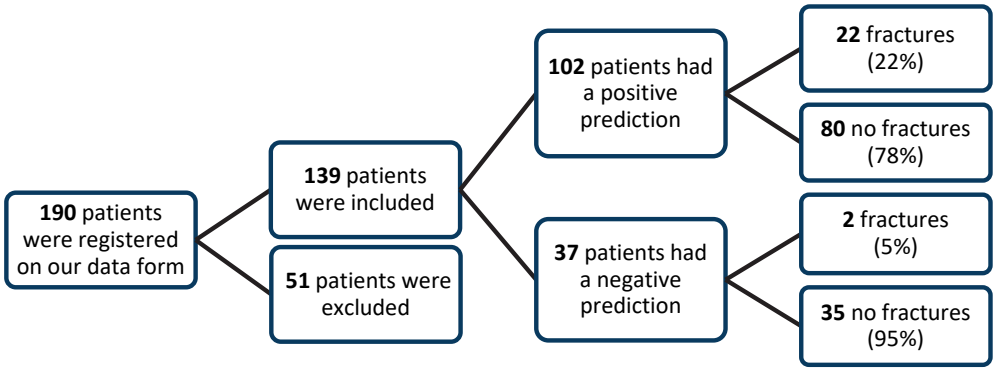

Figure 1. Flow diagram of patient inclusion and fracture prediction.

Table 1. Baseline characteristics stratified by prehospital prediction.

	Positive prediction	Negative prediction
Number	102	37
Median age (IQR*)	41 (22–60)	23 (18–46)
Male	60%	70%
MOI**		
High-energy trauma	42 (41%)	17 (46%)
Isolated blunt trauma	43 (42%)	11 (30%)
Lateral impact on vertebral column	5 (5%)	3 (8%)
Other high-energy trauma	12 (12%)	6 (16%)

* InterQuartile Range: 25 and 75th percentile
** Mechanism Of Injury

Table 2. Prehospital prediction of a spine fracture by paramedics.

	Definitive diagnosis		
	Fracture	No fracture	Total
Paramedic prediction: fracture	22	80	102
Paramedic prediction: no fracture	2	35	37
Total	24	115	139

Table 3. Details of spine fractures in patients with a negative prediction.

Patient	MOI*	Fracture type	Treatment
Male, 46 years	4-meter fall	T7 compression	Pain relief
Male, 69 years	2.5-meter fall	T11, L2, L4 compression	Orthesis

* Mechanism Of Injury

Discussion

This study demonstrates that paramedics can predict the presence of a spinal fracture with a low degree of accuracy, as demonstrated by the accuracy of 41%. The decision to perform prehospital spine immobilization is currently based on PHTLS criteria, which were previously reported to have an accuracy of 66%.[19] This figure was supported by a systematic review conducted in 2012.[22] The low accuracy of the prehospital evaluations by the paramedics in the current study suggests that implementation of a protocol based on paramedics predictions could not reduce the overuse of spine immobilization. The sensitivity in this study (92%) is similar to earlier findings from Domeier et al.,[19] which demonstrates that a paramedic-prediction approach will not limit sensitivity compared with current protocols. Michaleff et al. also reported a similar sensitivity to our study, although their investigation was limited to cervical spine fractures.[22]

In the present study we found that spine fractures are falsely predicted in 70% of trauma patients. Although this specificity of 30% seems low, it is in line with the results of previous studies that have looked at current guidelines.[19, 22, 27] Furthermore, the NPV of paramedic spine fracture evaluations reported here (95%) is the same as that reported in the current protocol for spine immobilization.[1, 19]

Paramedics failed to predict spine fractures in two patients, mainly because the symptoms were mild at initial presentation and a painful distracting injury was present. At the three-month follow-up, only one of these patients still had symptoms, while the other had fully recovered. None of these patients sustained spinal cord injury.

One limitation of this study was the high number of exclusions. The main reason for exclusion was the absence of a completed data form. Another limitation of our study is that we did not consider how many years of experience the paramedics had; it is possible that more experienced paramedics can more accurately predict spinal fractures in trauma patients. In addition, patients did not receive a CT scan of the whole spine, only of the segments that had an indication for this type of imaging. Some spine fractures may therefore have been missed, although the clinical relevance of a missed fracture is questionable. The fact that this study was performed in a level II trauma center means that patients with extreme severe trauma and a high chance of positive prediction are excluded. The high prevalence of spine fractures in this study (17%) compared to the prevalence found in literature (3-5%) could be caused by the patient selection in our study.[28] We selected all patients that we prehospital immobilized according to our national protocol. However, the recent numbers of spinal fractures are increasing due to osteoporosis and increased use of computed tomography scans.[29]

This study could be added to by further investigating how accurately paramedics can predict the location of spine fractures and whether cervical, thoracic or lumbar fractures are easiest to predict. Future studies should analyze a larger number of paramedics and take the fracture location and years of experience into account.

Conclusion

Paramedics cannot accurately predict spinal fractures based on the trauma mechanism and clinical symptoms.

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CHAPTER 5

Accuracy of prehospital spine immobilization protocols following blunt trauma: a systematic review

J.G. ten Brinke, E.A.J. van Rein, G. Slinger, M. Hogervorst, J.C. Goslings, T.P. Saltzherr

Submitted

Abstract

Background

Current international guidelines state that all trauma patients should be immobilized by emergency medical services to prevent neurologic deterioration in case of suspected unstable spinal fractures. However, only 2–3% of patients receiving prehospital spinal immobilization are subsequently diagnosed with spinal fractures. Spinal immobilization can have severe negative side effects, including pressure sores, raised intracranial pressure and airway management difficulties. Global implementation of the most accurate prehospital spinal immobilization protocol could prevent unnecessary immobilization. This systematic review was performed to determine which protocol is most accurate in the prehospital setting.

Methods

A systematic literature search was performed. We included all studies that described the accuracy of prehospital spinal immobilization protocols for identifying patients with a spinal injury among those suffering blunt trauma. The quality of the studies was assessed using the QUADAS-2 checklist.

Results

Eleven studies were eligible for qualitative synthesis. A critical appraisal of these studies demonstrated that the majority were of limited quality. Nine different spinal immobilization protocols were analysed, most with similar criteria. Incidence of spinal fractures in the studies was 0.5–100%. Protocol-based and immobilization-based quality analysis showed high sensitivity and low specificity, resulting in moderate accuracy for most protocols.

Conclusions

This review provides insufficient evidence to determine the most accurate protocol in the prehospital setting. We recommend that future studies are conducted with large sample sizes to generate a tailor-made protocol that is sufficiently specific such that only patients with a clinically relevant fracture will be immobilized.

Manuscript

Introduction

According to current international guidelines, all trauma patients at risk of spinal fractures should receive spinal motion restriction. Such interventions are provided by emergency medical services (EMS) to prevent neurologic deterioration in case of unstable spinal fractures.[1-6] Over five million patients in the United States undergo prehospital spinal immobilization each year.[1] Since only approximately 2–3% of these immobilized adult patients are subsequently diagnosed with a spinal fracture by radiographic imaging,[7] many patients are immobilized unnecessarily. Spine immobilization can cause/have severe side effects, including pressure sores, raised intracranial pressure and difficulties in airway management.[8-11] Besides causing discomfort to the patient, immobilization in the prehospital setting may take up valuable time.[12] While this is justified when the benefits outweigh the harms, research conducted over the past decade has raised questions regarding these benefits.[13-18]

As prehospital treatment of potential spinal fractures continues to evolve, successive consensus statements and international guidelines continue to support the use of accurate prehospital immobilization protocols.[19-21] The guidelines state that such protocols must identify patients in need of spinal immobilization. On the other hand, an accurate prehospital immobilization protocol should also prevent unnecessary immobilization of patients and thereby reduce the chances of potential harmful secondary effects of spinal immobilization.

The criteria used by the EMS in prehospital spinal immobilization protocols vary between different countries.[3, 4, 22-24] Many of these protocols were initially designed to indicate which patients require radiological imaging in the emergency department.[25] At a later stage, they were validated as spinal clearance and immobilization protocols in the prehospital setting.[26, 27] Most protocols include a set of patient characteristics and symptoms, such as the National Emergency X-Radiography Utilization Study (NEXUS) criteria or the Canadian C-spine Rule (CCR). The NEXUS criteria and the CCR are the most widely implemented criteria used in spinal immobilization protocols, either in their original or modified states.[26-29]

Nevertheless, consensus is lacking regarding the most accurate protocol for immobilization of the spine in the prehospital setting. Therefore, our aim was to determine the quality of prehospital spinal immobilization protocols in terms of their sensitivity, specificity and accuracy for identifying trauma patients with a spine injury requiring immobilization.

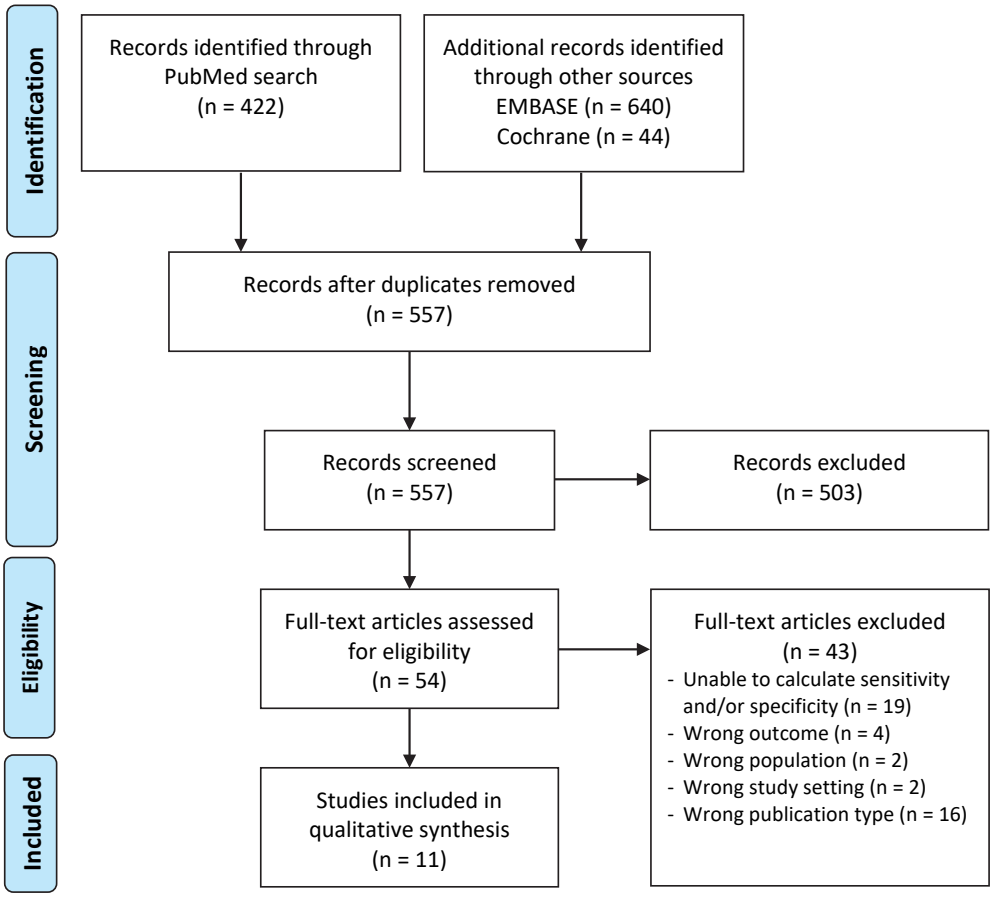
Methods

Literature search and study selection

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[30] A flow diagram based on the PRISMA guidelines and showing the process of study selection is provided in Figure 1. The search was performed in Medline (PubMed), EMBASE (Ovid) and the Cochrane Library on 31

March 2020. The search strategy searched for terms describing the use of clinical decision rules or protocols in the prehospital setting. The studies included in our review met the following criteria: the study used a spinal immobilization protocol in the prehospital setting following blunt trauma; it included data on prehospital spinal immobilization; it included data on confirmed diagnosis of spinal fractures and it included data on the diagnostic accuracy of the protocol (sensitivity and specificity). Studies written in languages other than English were excluded. 'Grey' literature (i.e. conference abstracts, editorials and dissertations) was also excluded. Two independent reviewers (JB and ER) screened all studies for eligibility. Disagreements between the two reviewers were addressed by discussion until consensus was reached. Following the selection of studies to be screened by full text, we also cross-referenced articles that included references to these studies to identify any potentially relevant articles missed by the database search.

Figure 1. PRISMA 2009 Flow Diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097
For more information, visit www.prisma-statement.org.

Methodological quality assessment

The methodological quality of the studies that we included was assessed using the 11-item Quality Assessment of Diagnostic Accuracy Studies 2 (QUADAS-2) criteria.[31] The QUADAS-2 consists of four key domains covering patient selection, index test, reference standard, and flow and timing. The domains are rated as having a 'low', 'high' or 'unclear' risk of bias, and 'low', 'high' or 'unclear' concerns regarding applicability. Two reviewers (JB and ER) rated each study independently and disagreements were resolved through discussion until consensus was reached. Total risk of bias and applicability was scored per item and an overall score was calculated for each domain.

Data extraction and analysis

Data was extracted by one author and verified by a second. For each index test with its reference standard, we extracted sensitivity, specificity and accuracy, either by direct transmission or through calculation. We then used two methods to analyse the quality of the protocols: a protocol-based method and an immobilization-based method. The protocol-based method assessed data on the accuracy of the protocol itself, regardless of actual immobilization. The immobilization-based method assessed data on daily practice: the number of patients who were immobilized by EMS providers using the specific protocols. Lastly, compliance to the protocol was analyzed, this is defined as the spinal immobilisation by EMS providers of a patient meeting the protocol criteria for immobilization.

Results

Literature search and study selection

The literature search retrieved a total of 557 unique studies (Figure 1). Screening of titles and abstracts led to the exclusion of 503 records. Assessment of the remaining 54 full texts resulted in 11 studies eligible for qualitative analysis. No additional studies were included after cross-referencing.

Study characteristics

The studies were published between 1998 and 2017. Six studies collected data prospectively,[28, 29, 32-35] while five studies collected data retrospectively.[36-40] The baseline characteristics are shown in Table 1, with full details provided in Appendix 2.

Quality assessment

The results of the methodologic quality assessment using the QUADAS-2 checklist are shown in Table 2. In nine studies the risk of bias was high. Two studies had a low risk of bias. Eight studies also had a high risk of applicability concerns.

In terms of risk of bias, several studies had a risk of selection bias. Two studies only included immobilized patients [28, 34] and two only included patients with a spinal fracture,[36, 39] thus all introducing selection bias (Table 1). A further two studies only included patients transported to a higher-level trauma centre,[35, 38] which may have introduced selection bias as these

patients potentially had severe injuries. Almost all studies included patients of all ages, except for two.[33, 40]

While nearly all eleven studies analysed a different index test, the criteria overlapped between the different protocols (Table 3).

None of the studies used the same reference standard for the entire study population. Diagnosis was often based on evaluation of the patient by a specialist; radiographs were not obtained for all patients and the use of diagnostic tools was not reported. Four studies used ICD-9 codes, which may have introduced bias since accuracy depends on the quality of the registration and the diagnostic tools used.[29, 36, 39, 40]

Table 1. Baseline characteristics of all included articles

Study	Study design	Patients (n)	Study population	Incidence of spinal injury (%)
Burton et al. (2006)	Prospective cohort	31,885	All trauma patients of all ages transported to a hospital	0.5
Domeier et al. (2002)	Prospective cohort	8,975	Trauma patients, immobilized and transported by the EMS	3.3
Domeier et al. (2005)	Prospective cohort	13,357	Trauma patients with a complete documented spine injury assessment, transported by the EMS	3.0
Fung Kon Jin et al. (2007)	Retrospective chart review	238	Trauma patients with a spinal fracture, immobilized by the EMS	100
Meldon et al. (1998)	Prospective cohort	190	Blunt trauma patients transported to a level I trauma centre	2.6
Muhr et al. (1999)	Retrospective cohort	281	All trauma patients not meeting the trauma system criteria for severely injured patients	2.5
Myers et al. (2009)	Retrospective cohort	942	All trauma patients transported to a level I trauma centre	4.6
Stroh et al. (2001)	Retrospective chart review	504	All patients transported to hospitals by EMS personnel, with or without spinal immobilization with a cervical spine fracture	100
Tatum et al. (2016)	Retrospective cohort	997	Blunt trauma patients ≥ 18 yrs transported by the EMS	2.2
Ten Brinke et al. (2017)	Prospective cohort	139	Trauma patients immobilized at the ED	17.2
Vaillancourt et al. (2009)	Prospective cohort	1,949	Alert, stable and cooperative patients > 16 yrs, transported by the EMS after blunt trauma	0.6

N= number; EMS = emergency medical services; ED = emergency department; yrs = years

Table 2. Quality assessment using the QUADAS-2 checklist

	Domain 1 Patient selection					Domain 2 Index test(s)			Domain 3 Reference standard			Domain 4 Flow and timing						
	Risk of bias				Appl	Risk of bias		Appl	Risk of bias		Appl	Risk of bias						
	Was a consecutive or random sample of patients enrolled?	Was a case-control design avoided?	Did the study avoid inappropriate exclusions?	Could the selection of patients have introduced bias?	Is there concern that the included patients do not match the review question?	Were the index test results interpreted without knowledge of the results of the reference standard?	Could the conduct or interpretation of the index test have introduced bias?	Is there concern that the index test, its conduct, or interpretation differ from the review question?	Is the reference standard likely to correctly classify the target condition?	Could the reference standard, its conduct or its interpretation have introduced bias?	Is there concern that the target condition as defined by the reference standard does not match the review question?	Was there an appropriate interval between index test and reference standard?	Did all patients receive a reference standard?	Did patients receive the same reference standard?	Were all patients included in the analysis?	Could the patient flow have introduced bias?	TOTAL BIAS	TOTAL APPLICABILITY
Burton et al. (2006)	?	+	+	Low	Low	+	Low	Low	?	?	High	+	+	?	+	Low	Low	Int
Domeier et al. (2002)	–	+	–	High	High	+	Low	?	–	High	Low	?	+	–	+	High	High	High
Domeier et al. (2005)	+	+	–	Low	Low	+	Low	Low	–	High	Low	+	+	–	+	Low	Low	Low
Fung Kon Jin et al. (2007)	–	+	+	Low	High	–	High	Low	–	High	High	?	+	?	+	High	High	High
Meldon et al. (1998)	–	+	?	High	High	+	Low	Low	–	High	High	+	+	–	+	High	Int	High
Muhr et al. (1999)	–	+	?	High	High	+	Low	Low	?	?	?	+	?	?	+	?	High	High
Myers et al. (2009)	–	+	+	Low	High	–	High	High	–	High	High	+	+	–	+	Low	Int	High
Stroh et al. (2001)	–	+	+	High[A]	High	+	Low	Low	–	High	High	+	+	?	+	Low	High	Int

Tatum et al. (2017)	–	+	+	Low	High	+	Low	Low	–	High	High	+	+	?	–	High	Int	High
Ten Brinke et al.(2018)	–	+	+	High[B]	High	+	Low	Low	–	High	High	+	+	–	+	Low	High	High
Vaillancourt et al.(2009)	–	+	+	Low	High	+	Low	Low	–	High	High	+	+	–	–	High	Int	High

Appl = concern regarding applicability; Int = intermediate; + = low risk of bias; – = high risk of bias; ? = unclear risk of bias
Total risk of bias and concern regarding applicability was scored per item and an overall score was calculated for each domain. The overall score of domain 1 was deemed *low* risk of bias or applicability concerns in case of ≥ 2 times a '+' and *high* in case of < 2 times a '+'. Here a '?' was considered '–'. The overall score of domains 2 and 3 was considered a *low* risk of bias or applicability concerns in case of a '+', '?' in case of a '?' and *high* in case of '–'. The overall score of domain 4 was deemed *low* in case of ≥ 2 times a '+'. In case of two times a '+' and two times a '–' it was deemed *intermediate* and in case of ≥ 2 times a '–' it was deemed a *high* risk of bias or applicability concerns.
[A] Although this study scored well on domain 1, we scored a *high* risk of selection bias since only patients with a cervical spine fracture, dislocation or spinal cord injury without radiographic abnormality were included.
[B] Although this study scored well on domain 1, we scored a *high* risk of selection bias since only immobilized patients were included.

Table 3. Characteristics of the prehospital spinal immobilization protocols

		Index test							Reference test
Study	**Protocol**	**Mental status**	**Neurologic**	**Spinal**	**Distracting injury**	**MOI**	**Intoxication**	**Other**	
Burton *et al.* (2006)	NEXUS criteria + MOI	Altered	Abnormal sensory/ motor exam	Spine pain/ tenderness	Distracting injury	MOI	Evidence of intoxication		ICD-9 diagnostic coding for presence of a spinal fracture
Domeier *et al.* (2002)	NEXUS criteria	Altered	Focal neurologic deficit	Spine pain/ tenderness	Suspected extremity fracture		Evidence of intoxication		Spinal fracture or spinal cord injury diagnosed by radiology or specialist evaluation
Domeier *et al.* (2005)	NEXUS criteria	Altered	Neurologic deficit	Spine pain/ tenderness	Suspected extremity fracture		Evidence of intoxication		Spinal fracture or spinal cord injury diagnosed by radiology or specialist evaluation
Fung Kon Jin *et al.* (2007)	NEXUS + age	Altered	Neurologic deficit	Spine pain on palpation	Distracting injury		Evidence of intoxication	Age ≥ 65 years	ICD-9 diagnostic coding for presence of a spinal fracture
Meldon *et al.* (1998)	Cleveland EMS/Fire Department protocol	Altered	Focal neurologic deficit	Spine pain/ tenderness		MOI			Cervical spine fracture diagnosed by radiology or specialist evaluation
Muhr *et al.* (1999)	NEXUS criteria	Altered or loss of consciousness	Focal neurologic deficit	Spine pain/ tenderness or pain with range of motion	Distracting injury		Evidence of intoxication		Spinal fracture or neurologic deficit diagnosed by medical record review (not further specified)
Myers *et al.* (2009)	Institutional spinal immobilization guideline	Altered		Spine pain/ tenderness	Distracting injury		Evidence of intoxication	Symptoms of shock	Spinal fracture diagnosed by radiology or specialist evaluation

Stroh *et al.* (2001)	Selective spine immobilization clearance protocol (1990)	Altered	Focal neurologic deficit	Spine pain/ tenderness	Severe head/ facial trauma Significant multiple trauma				ICD-9 diagnostic coding for presence of a cervical spine fracture or spinal cord injury without radiographic abnormality
Tatum *et al.* (2016)	LADHS guidelines for cervical SMR	Altered	Abnormal sensory/ motor exam	Spine pain		MOI	Evidence of intoxication	Age ≥ 65 years	ICD-9 diagnostic coding for presence of cervical spinal injury
Ten Brinke *et al.* (2017)	Prediction by paramedics							Prediction by paramedics	Spinal fracture or spinal cord injury diagnosed by radiology or specialist evaluation
Vaillancourt *et al.* (2009)	Canadian C-Spine Rule		Focal Neurologic deficit	Spine pain/ tenderness Unable to rotate the neck > 45 degrees		MOI		Age ≥ 65 years	Spinal fracture or spinal cord injury diagnosed by radiology or specialist evaluation

MOI = mechanism of injury; NEXUS = National Emergency X-Radiography Utilization Study; EMS = emergency medical services; LADHS = Los Angeles Department of Health Services; SMR = spinal motion restriction; ICD = International Classification of Diseases

In all studies, applicability concerns were raised by the inclusion criteria, which meant that the study populations were not representative of the entire population of patients that EMS providers normally assess in daily practice. An additional problem in terms of quality was that the outcome of the studies differed (Table 4): three studies described all acute spine injuries (any fracture, dislocation or ligamentous instability),[28, 32, 37] while others only reported on fractures [29, 34, 36, 38] or cervical spine injury.[33, 35, 39, 40]

Protocol-based analysis of protocol quality

The protocol-based analysis of each study assessed protocol quality regardless of which patients were actually immobilized. For most studies, the protocol was used to assess patients prospectively.[28, 32-34] Sensitivity, specificity and accuracy are shown in Table 4a: sensitivity ranged from 84% to 100% (mean 94%), specificity from 30% to 61% (mean 35%) and accuracy from 37% to 62% (mean 45%).

Myers *et al.* reported the lowest sensitivity: 83.7%. While the inclusion of an age extreme criterion in this study (≥ 64 years) would have increased the sensitivity to 97.7%, it would also have increased the number of those requiring immobilization by 42%.[38] Protocols that indeed included an age criterion resulted in higher sensitivity rates – even up to 100%.[33] Missed fracture rates ranged from 0% to 16%. Most studies reported the type and the management of missed fractures.[28, 32-34, 36] Vaillancourt et al. reported no missed fractures. In the study of Myers *et al.*, it was unclear what type of fractures were missed and what the consequences were.[38] Most of the missed fractures reported in the other studies were treated with a collar or orthesis. Domeier et al. reported the need for a halo frame or surgical stabilization in 8%–13% of patients with a missed fracture.[28, 32] None of the studies reported an increase in neurological symptoms among patients with a missed fracture.

Immobilization-based analysis of protocol quality

Our immobilization-based analysis of each study assessed protocol quality in terms of the proportion of patients immobilized by EMS providers. Sensitivity, specificity and accuracy are shown in Table 4b: sensitivity ranged from 87% to 100% (mean 94%), specificity from 17% to 61% (mean 42%) and accuracy from 19% to 72% (mean 45%).

Three studies compared the use of a new, more selective protocol with previously used protocols, all three of which led to a reduction in the proportion of immobilized patients by 33% to 59%, while missed fractures ranged from 0% to 13%.[32, 37, 38] Five of seven studies reported on the different types of missed fractures and how they were managed.[32, 34, 35, 39, 40] For the other two studies, it was unclear what types of fractures were missed and what the consequences were.[37, 38] Stroh *et al*. reported an operative fixation in one out of five missed fractures.[39] None of the studies reported an increase in neurological symptoms among patients with a missed fracture. Ten Brinke *et al*. evaluated the accuracy with which EMS providers could predict a spinal fracture after prehospital examination. The results of their study suggest that EMS providers can predict the presence of spinal fracture with an accuracy of 41%.[34]

Table 4a. Accuracy of prehospital spinal immobilization protocols (regardless of actual immobilization)

Study	Outcome measurement	TP	FP	FN	TN	Sensitivity (%)	Specificity (%)	Accuracy (%)
Domeier *et al.* (2002)	Any spinal fracture or spinal cord injury	280	5,642[A]	15	3,038[A]	94.9	35.0	37.0[A]
Domeier *et al.* (2005)	Any spinal fracture or spinal cord injury	378	7,754	37	5,188	91.1	40.1	41.7[A]
Fung Kon Jin *et al.* (2007)	Any spinal fracture							
	NEXUS	NR	0	NR	0	95.8	-	-
	NEXUS with age	236	-	2	-	99.2	-	-
Myers *et al.* (2009)	Any spinal fracture	36	348	7	551	83.7	61.3[A]	62.3[A]
Ten Brinke *et al.* (2017)[B]	Any spinal fracture	22	80	2	35	91.7	30.4	41.0
Vaillancourt *et al.* (2009)	Any unstable cervical spinal injury	12	924	0	693	100	42.9	43.3

TP = true positives; FP = false positives; FN = false negatives; TN = true negatives; NR = not reported
[A] Calculated by authors of current paper
[B] Based on EMS judgement and not the protocol used

Table 4b. Accuracy of prehospital spinal immobilization (number of patients immobilized by EMS providers)

Study	Outcome measurement	TP	FP	FN	TN	Sensitivity (%)	Specificity (%)	Accuracy (%)
Burton *et al.* (2006)	Any spinal fracture	134	12,851	20	18,880	87.0	59.5	59.6[A]
	Unstable spine fracture	16	12,969	1	18,889	94.1	59.3	59.3[A]
Domeier *et al.* (2002)	Any spinal fracture or spinal cord injury	295	8,680	-	-	-	-	-
Domeier *et al.* (2005)	Any spinal fracture or spinal cord injury	382	7,804	33	5,138	92.1	39.7	41.3[A]
Meldon *et al.* (1998)	Cervical spinal injury	5	141	0	44	100[A]	23.8[A]	25.8[A]
Muhr *et al.* (1999)	Spinal injury	7	176	1	97	87.5[A]	35.5[A]	37.0[A]
Myers *et al.* (2009)	Any spinal fracture	364	353	9	546	97.6[A]	60.7[A]	71.5[A]
Stroh *et al.* (2001)	Cervical spinal fracture or spinal cord injury	499	-	5	-	99.1	-	-
Tatum *et al.* (2016)	Cervical spinal injury	20	805	2	170	90.9	17.4	19.0
Ten Brinke *et al.* (2017)	Any spinal fracture	24	115	-	-	-	-	-

EMS = emergency medical services; TP = true positives; FP = false positives; FN = false negatives; TN = true negatives;
[A] Calculated by authors of current paper

Compliance

Only a few studies assessed either the judgement of EMS providers [34] or their compliance with the protocol.[32, 35, 37, 38]

Myers *et al*. found non-compliance with the protocol in one out of five patients. Of these patients who were – wrongly – not immobilized, 25% were later found to have a spinal fracture. Intoxication was the most reported reason for non-compliance. However, for 30%, clear documentation of reasoning was absent. Whether or not a patient was immobilized also affected the use of additional diagnostic tools at the hospital. For example, if EMS providers were non-compliant with the protocol and did not immobilize the patient, the patient was 13% less likely to receive a radiograph than a patient who was correctly immobilized. Conversely, non-compliance with the protocol resulting in immobilization of patients resulted in a 26% higher chance of a radiograph.

Domeier *et al*. found that EMS providers immobilized 12% of patients where this was not required by the protocol, and failed to immobilize 7% where immobilization was required.[32] They also found that among patients with a spinal injury and a positive assessment, 3% were not immobilized (non-compliance); none had a spinal cord injury. Consequently, the authors concluded that the use of a more selective immobilization protocol resulted in spinal immobilization for most patients with spinal injury; among patients with a negative assessment, less than 1% had a spinal injury.

Vaillancourt *et al*. found that the protocol was misinterpreted by EMS providers in 16% of the patients, resulting in them not being immobilized while they should have been according to the protocol.[33] These patients were omitted from the analysis in the original paper.

Meldon *et al*. compared the judgement of EMS providers with that of emergency physicians. In their study, for patients who had been immobilized, emergency physicians did not agree with the need for immobilization in 12% of cases. For patients who had arrived without spinal immobilization, emergency physicians subsequently immobilized 23% at the hospital. Even though all patients with a cervical spine injury were immobilized, these results show that the application of and/or compliance with the protocol differs between EMS providers and emergency physicians.

Discussion

This systematic review analysed eleven studies that reported on prehospital spinal immobilization protocols. The analysis showed that the protocols used in these studies had high sensitivity and low specificity, resulting in moderate accuracy for most protocols. A critical appraisal of the studies demonstrated that two of them stand out in terms of quality and applicability: Burton *et al*.[29, 32] and Domeier *et al*.'s 2005 study. It was difficult to rank the other nine studies due to their limited methodological quality and high concerns regarding applicability.

In 1966, Geisler was the first to publish an article on the prevention of neurological deterioration using prehospital immobilization.[41] While immobilization minimizes spinal movement and therefore reduces risk of secondary injury, high-level evidence for the possible improvement in patient outcomes is lacking.[13, 15, 18, 42] Because the supporting and opposing evidence regarding prehospital immobilization is equally divided, the present situation appears to have reached a deadlock.[18] However, a solution to this issue is crucial given the possibly devastating results of not immobilizing patients with a spinal injury on the one hand, and unnecessary immobilization and its consequences on the other. In this review, we assessed the quality of different prehospital spinal immobilization protocols used to identify patients in need of immobilization. The protocol quality was assessed in terms of sensitivity, specificity and accuracy. A protocol with high sensitivity will identify patients in need of immobilization – those with a spinal injury – to protect them from neurological deterioration. On the other hand, a protocol with high specificity will ensure no unnecessary immobilization. Since immobilization can have adverse effects and is time consuming,[8-12] efforts should be made to reduce unnecessary immobilization. An adequate protocol is the foundation of a competent/reasonable immobilization policy.

As shown by our critical appraisal, most studies had limited methodological quality. The majority of studies did not include all of the trauma patients transported to all trauma centres in a trauma region. Instead, the studies included specific subgroups of patients or a specific type of trauma centre. The inclusion of only those patients transported to a higher-level trauma centre potentially excludes a key patient population. The quality of an accurate immobilization protocol can only truly be judged based on all trauma patients transported to all levels of trauma centres in the region, as well as on EMS compliance with the protocol. For example, Domeier *et al*.[32] included all trauma patients transported by the EMS to all levels of trauma centres in a specific region. This study design guarantees accurate analysis of protocol accuracy and compliance. However, their study only included patients with a documented spinal injury assessment. Reasons for missing assessments were not specified, which may have introduced selection bias. Burton *et al*.[29] included trauma patients of all ages transported to a hospital. However, the number and level of trauma centres was not reported, which may also have introduced selection bias. Myers *et al*. may have introduced selection bias by excluding 15% of all patients, as they did not have a documented spinal injury assessment. The majority of studies did interpret the index test results without knowledge of the results of the reference standard. In two studies, EMS records were retrospectively analysed.[36, 38] For example, Myers *et al*.[38] did not record whether and how the EMS providers documented the presence or absence of the protocol's criteria, and this could have led to bias. None of the studies used the same reference standard for the whole study population, and a gold standard as reference test was missing. Michaleff *et al*.[43] provided an 'Ideal diagnostic test accuracy flow chart for the Canadian C-Spine Rule and NEXUS'. This flow chart recommends the use of radiographic imaging as a reference test and outlines an optimal study design for comparing two protocols. This allows for accurate data collection and unbiased results.

Regarding protocol-based quality, sensitivity was high for most protocols, while specificity varied. As expected, addition of a criterion, e.g. age, increased the sensitivity up to 100%, but reduced specificity. Immobilization-based studies showed similar sensitivity rates, specificity varied more. Furthermore, compliance to the protocol is crucial; , it is the EMS provider that ultimately decides whether or not to immobilize the patient. If EMS providers do not comply with the protocol,[44-46] even the most accurate protocol will not lead to effective immobilization. Since the success of protocols relies heavily on the interpretation of EMS providers, continuing education and the provision of quality measures could be key routes to improving compliance.

Determining the best protocol will most likely rely on choosing the optimal cut-off point. This could be a cut-off that provides high sensitivity to ensure immobilization of most patients with a spinal fracture, but at the cost of lowering specificity. Or it could be a cut-off that provides high specificity to minimize unnecessary immobilization, at the cost of lower sensitivity. Solving this dilemma requires robust assessment of the numbers of missed fractures and of the consequences of such missed fractures and also depends on other factors such as, costs, available supplies. Although two studies provided no data on the type and consequences of these missed fractures,[37, 38] most of the studies analysed here did report the numbers of missed fractures. The majority of missed spine injuries were treated with basic immobilization or pain control. For example, Burton *et al*.[29] missed 13% of spinal fractures, but of a total of 32,000 trauma patient encounters, only one patient had an unstable spinal fracture without spinal cord damage.

To be useful, the spinal immobilization protocols must identify patients with significant spine injuries of the entire spine. Four studies included only cervical spine injuries.[33, 35, 39, 40] However, a spinal immobilization protocol that is used to select patients for prehospital immobilization would ideally assess the spine as a whole.

Some limitations of this systematic review need to be addressed. The major limitation of this review was the heterogeneity of the included studies. The studies used different protocols, definitions, selection criteria and patient populations, making it impossible to compare them directly. As a consequence, it was impossible to recommend the best protocol. Another limitation is the possibility of publication bias: studies reporting limited protocol performance might be missing from our review. The possibility of publication bias is also increased by the fact that we excluded 'grey' literature. Another main source of bias is the fact that this review included both implementation and validation studies. Validation studies are performed during protocol development before implementation is in order. Although validation studies do provide valuable information and are an important part of evaluating the performance of a clinical decision rule, they can only report on hypothetical rather than actual situations.

Future research should focus on generating and improving prehospital immobilization protocols. Based on the results of this review, we provide two key recommendations. Firstly, to minimize selection bias when assessing immobilization protocols, studies should include all trauma patients and levels of trauma centres within a specific region. Secondly, studies should also

evaluate all steps of the immobilization process: the quality of the protocol itself, compliance with the protocol and the consequences of compliance. With these recommendations applied, efforts should be made to create a protocol that guarantees immobilization of patients with a spinal fracture and that prevents unnecessary immobilization. With large sample sizes, a more tailor-made protocol can be built that is sufficiently specific such that only patients with a clinically relevant fracture will be immobilized.

This systematic review analysed eleven studies evaluating prehospital spinal immobilization protocols. It showed that the protocols had high sensitivity and low specificity, resulting in moderate accuracy for most protocols. Future studies with large sample sizes should be conducted to generate a tailor-made protocol that is sufficiently specific such that only patients with a clinically relevant fracture will be immobilized.

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Appendix - study characteristics

Title	A Statewide, Prehospital Emergency Medical Service Selective Patient Spine Immobilization Protocol
Authors	Burton JH, Dunn MG, Harmon NR, Hermanson TA, Bradshaw JR
Year	2006
Methods	
Study design	Prospective cohort
Setting	Not reported
Participants	All trauma patients of all ages transported to a hospital
Test methods	Index test: 'NEXUS-like' decision instrument; EMS providers documented the decision to enact spine immobilization Reference standard: the presence of a spinal fracture was determined by ICD-9 diagnostic coding specific for spine fracture
Outcomes	Sensitivity, specificity, PPV, NPV
Results	
Participants	31,885 trauma patients
Test results	For any acute spine fracture: sensitivity 87.0%, specificity 59.5%, PPV 1.0%, NPV 99.9% For unstable acute spine fractures: sensitivity 94.1%, specificity 59.3%, PPV 0.1%, NPV 99.9%
Other information	
Funding	None
QUADAS-2	
Patient selection	All trauma patients transported to a hospital were included; however, which hospitals were included was not reported, possibly introducing selection bias
Index test	EMS providers documented the decision to enact with the spine immobilization protocol or not, leading to a low risk of bias
Reference standard	The diagnostic tools used to determine the presence or absence of a spinal fracture were not reported, possibly introducing bias
Flow and timing	All patients were included in the analysis

Abbreviations: NEXUS = National Emergency X-Radiography Utilization Study; EMS = emergency medical services, PPV = positive predictive value, NPV = negative predictive value

Title	Multicenter Prospective Validation of Prehospital Clinical Spinal Clearance Criteria
Authors	Domeier RM, Swor RA, Evans RW, Hancock JB, Fales W, Krohmer J, Frederiksen SM, Rivera-Rivera EJ, Schork MA
Year	2002
Methods	
Study design	Prospective cohort
Setting	17 hospitals and 23 transporting ambulance services in 7 mixed urban/suburban/rural counties in southern Michigan, United States
Participants	All patients of all ages with a traumatic injury and spine immobilization performed in the prehospital setting
Test methods	Index test: NEXUS criteria; EMS providers documented the presence or absence of these criteria Reference standard: the presence of a spinal fracture determined by positive radiographic evidence on the basis of a radiologist's report; the presence of a spinal cord injury was based on a specialist evaluation. Patients who were cleared clinically (without radiographs) in the emergency department were assumed to have no spinal injury
Outcomes	Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV)
Results	
Participants	8,975 patients with spinal immobilization transported to a hospital by ambulance services
Test results	Sensitivity 94.9%, specificity 35.0%, PPV 4.7%, NPV 99.5%
Other information	
Funding	"Supported by the Saint Joseph Mercy Hospital Emergency Department Research Fund, the Clinical Research Fund, and the Saint Joseph Mercy Hospital Auxiliary Gift Fund"
QUADAS-2	
Patient selection	All trauma patients with spine immobilization, based on the existing EMS immobilization protocol. Patients were included if the EMS providers filled out the questionnaire where the presence or absence of the NEXUS criteria was documented. It is unclear for how many patients the questionnaire was not filled out and if all regional hospitals and ambulance services were included
Index test	The index test was reported by EMS providers in a standardized data questionnaire, leading to a low risk of bias
Reference standard	Radiologist reports of the radiographs were used as reference standard. Patients without radiographs were assumed to have no spinal injury; these patients were checked if they returned for treatment of a spine injury. Patients could have been returned to another hospital for diagnosis / treatment, possibly leading to missed spinal injuries
Flow and timing	Not all patients were diagnosed using the same reference standard; all patients were included in the analysis

Abbreviations: NEXUS = National Emergency X-Radiography Utilization Study; EMS = emergency medical services

Title	Prospective Performance Assessment of an Out-of-Hospital Protocol for Selective Spine Immobilization Using Clinical Spine Clearance Criteria
Authors	Domeier RM, Frederiksen SM, Welch K
Year	2005
Methods	
Study design	Prospective cohort
Setting	2-county, mixed, suburban/rural, EMS system with 5 hospitals (including 2 trauma centers) with 2 ground-transporting advanced life support ambulance services and 28 non-transporting first-response services
Participants	All trauma patients of all ages evaluated with the southeastern Michigan EMS spine injury assessment protocol
Test methods	Index test: NEXUS criteria; EMS providers documented the presence or absence of these criteria Reference standard: the presence of a spinal fracture determined by positive radiographic evidence on the basis of a radiologist's report; the presence of a spinal cord injury was based on a specialist evaluation. Patients who were cleared clinically (without radiographs) in the emergency department were assumed to have no spinal injury
Outcomes	Sensitivity and specificity
Results	
Participants	13,357 trauma patients transported by the EMS providers
Test results	Immobilization-based: sensitivity 91%, specificity 40% Protocol-based: sensitivity 92%, specificity 40%
Other information	
Funding	"This work was generously supported by the St. Joseph Mercy Hospital Emergency Department Research Fund and the Clinical Research Fund"
QUADAS-2	
Patient selection	All patients with a documented spine injury assessment were included; 15.4% of all patients however did not have it documented and were thus not included, possibly leading to selection bias
Index test	The spine injury assessment table completed by EMS providers provided the evidence of spine injury assessment components, as well as the subsequent use (or non-use) of spine immobilization, leading to a low risk of bias
Reference standard	Radiologist reports or specialist evaluation provided evidence of any diagnosis of spine fracture of spinal cord injury; the diagnostic tools used to determine the presence or absence of a spinal injury were not reported, possibly introducing bias
Flow and timing	All patients with a documented spine injury assessment were included in the analysis

Abbreviations: NEXUS = National Emergency X-Radiography Utilization Study; EMS = emergency medical services

Title	A Retrospective Study of Five Clinical Criteria and One Age criterion for Selective Prehospital Spinal Immobilization
Authors	Fung Kon Jin P, Goslings JC, Luitse J, Ponsen KJ
Year	2007
Methods	
Study design	Retrospective chart review
Setting	One level I trauma center (Academic Medical Centre Amsterdam) in the Netherlands, 5-year period
Participants	All patients of all ages admitted to the Academic Medical Centre with an acute spinal fracture, based on ICD-9 codes
Test methods	Index test: NEXUS criteria with additional age criterion (≥65 years)
Outcome	Sensitivity
Results	
Participants	238 blunt trauma patients with a spinal fracture
Test results	Sensitivity 99.2%
Other information	
Funding	None
QUADAS-2	
Patient selection	Patients were included based on the ICD-9 coding system for spinal injury
Index test	The criteria were retrospectively applied by researchers based on the prehospital ambulance forms and prehospital report in the medical files, leading to a high risk of bias
Reference standard	ICD-9 codes for spine injury were used as reference standard, which requires an accurate database. Since two patients were excluded because they did not have a fracture (despite being coded as if they did), it is also possible that patients with a fracture were missed
Flow and timing	Not all patients were included in the analysis: 90 patients were excluded (59 were transferred, 13 did not suffer from an acute fracture/trauma, 7 did not have a trauma, 5 had an isolated sacrum fracture, 4 had an isolated penetrating trauma, 2 did not have a fracture)

Abbreviations: ICD-9 = International Statistical Classification of Diseases, ninth revision, NEXUS = National Emergency X-Radiography Utilization Study

Title	Out-of-Hospital Cervical Spine Clearance: Agreement Between Emergency Medical Technicians and Emergency Physicians
Authors	Meldon SW, Brant TA, Cydulka RK, Collins TE, Shade BR
Year	1998
Methods	
Study design	Prospective cohort
Setting	One urban level I trauma center
Participants	All blunt trauma patients of all ages transported by the EMS or Fire Department to the urban level I trauma center
Test methods	Index test: Cleveland EMS/Fire Department protocol Reference standard: the presence of a spinal fracture was based on hospital reports; radiographs were not obtained for all patients
Outcome	Interrater agreement (kappa) between EMS and emergency physicians regarding prehospital cervical spine injury clearance
Results	
Participants	190 blunt trauma patients
Test results	Overall disagreement between EMS and emergency physicians regarding cervical spine injury prehospital clearance occurred in 23% (kappa 0.29, $p < 0.01$)
Other information	
Funding	Not reported
QUADAS-2	
Patient selection	Only patients transported to a level I trauma center were included, possibly leading to selection bias
Index test	The EMS providers prospectively completed a standardized data collection sheet noting the presence or absence of all criteria of the protocol separately, leading to a low risk of bias
Reference standard	The diagnostic tools used to determine the presence or absence of a spinal fracture were not reported, possibly introducing bias; radiographs were not obtained for all patients
Flow and timing	Not all patients were diagnosed using the same reference standard; all patients were included in the analysis

Abbreviations: EMS = emergency medical services

Title	Paramedic Use of Spinal Injury Clearance Algorithm Reduces Spinal Immobilization in the Out-of-Hospital Setting
Authors	Muhr MD, Seabrook DL, Wittwer LK
Year	1999
Methods	
Study design	Retrospective cohort
Setting	3 EMS services and 1 level II trauma center
Participants	All trauma patients of all ages transported to the emergency department by EMS services, except for patients meeting the trauma system criteria
Test methods	Index test: standard immobilization decision and algorithm-based immobilization. EMS providers documented criteria for instituting or withholding spinal immobilization and reported whether immobilization was indicated, but not done Reference standard: the presence of a spinal fracture based on hospital reports
Outcome	Multivariate logistic regression to predict the spinal immobilization status
Results	
Participants	281 trauma patients
Test results	Using the new algorithm-based immobilization protocol, a 33% reduction in immobilization was observed; older patients were slightly less likely to receive spinal immobilization
Other information	
Funding	Not reported
QUADAS-2	
Patient selection	Patients meeting the trauma system criteria were excluded, possibly introducing selection bias
Index test	EMS providers documented criteria for instituting or withholding spinal immobilization, with reasoning in prehospital setting, leading to a low risk of bias
Reference standard	The diagnostic tools used to determine the presence or absence of a spinal fracture were not reported, possibly introducing bias
Flow and timing	All patients were included in the analysis

Abbreviations: NEXUS = National Emergency X-Radiography Utilization Study; EMS = emergency medical services

Title	Efficacy and Compliance of a Prehospital Spinal Immobilization Guideline
Authors	Myers LA, Russi CS, Hankins DG, Berns KS, Zietlow SP
Year	2009
Methods	
Study design	Retrospective cohort
Setting	One level I trauma center
Participants	All trauma patients of all ages transported to the level I trauma center
Test methods	Index test: institutional spinal immobilization guideline Reference test: the presence of a spinal fracture based on radiographic findings and physician clearance without radiographs
Outcomes	Performance of EMS providers regarding spinal immobilization, compliance to the guideline
Results	
Participants	942 trauma patients
Test results	The guideline correctly predicted a spinal fracture in 83.7% of the patients. Of the patients meeting the criteria, 9.4% had a spinal fracture. Noncompliance with the guideline was found in 22.3% of the patients, of whom 25.0% had a spinal fracture
Other information	
Funding	Not reported
QUADAS-2	
Patient selection	Only patients transported to a level I trauma center were included, possibly leading to selection bias
Index test	The EMS records were retrospectively analyzed; it was not reported whether and how the EMS providers documented the presence or absence of the criteria of the protocol, leading to a high risk of bias
Reference standard	There was no follow-up of patients who did not undergo radiography in the emergency department, possibly resulting in missed injuries and therefore bias
Flow and timing	Not all patients were diagnosed using the same reference standard; all patients were included in the analysis

Abbreviations: EMS = emergency medical services

Title	Can an Out-of-Hospital Cervical Spine Clearance Protocol Identify All Patients With Injuries? An Argument for Selective Immobilization
Authors	Stroh G, Braude D
Year	2001
Methods	
Study design	Retrospective chart review
Setting	5 trauma-receiving hospitals in Fresno County
Participants	All patients of all ages with a cervical spine fracture transported to hospitals by EMS personnel, with or without spinal immobilization
Test methods	Index test: Fresno/Kings/Madera (FKM) EMS system which implemented a selective spine immobilization clearance protocol Reference standard: the presence of a spinal fracture was determined by ICD-9 diagnostic coding specific for spine fracture
Outcome	Sensitivity
Results	
Participants	504 patients of whom 499 arrived in cervical spine immobilization
Test results	Sensitivity 99.0%
Other information	
Funding	Not reported
QUADAS-2	
Patient selection	Only patients with a cervical spine fracture, dislocation or spinal cord injury without radiographic abnormality were included, possibly introducing selection bias
Index test	Out-of-hospital case reports, emergency department charts and nursing documentation were retrospectively reviewed by researchers to assess whether a patient was immobilized, leading to a high risk of bias
Reference standard	ICD-9 codes for spine injury were used as reference standard, which can lead to missing patients in case of miscoding; the diagnostic tools used to determine the presence or absence of a spinal fracture were not reported, possibly introducing bias
Flow and timing	The patients receiving immobilization without a fracture were not included

Abbreviations: EMS = emergency medical services; ICD-9 = International Statistical Classification of Diseases, ninth revision

Title	Validation of a Field Spinal Motion Restriction Protocol in a Level I Trauma Center
Authors	Tatum JM, Melo N, Ko A, Dhillon NK, Smith EJT, Yim DA, Barmparas G, Ley EJ
Year	2016
Methods	
Study design	Retrospective study
Setting	One level I trauma center (Cedars-Sinai Medical Center) in California
Participants	Patients with a blunt trauma and transported by emergency medical services, age ≥18, GCS ≥13
Test methods	NEXUS decision-making rules on arrival to the trauma center, regardless of immobilization before arrival. Patients with and without cervical spine injury were compared, as well as patients with or without immobilization in place upon arrival
Outcomes	Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV)
Results	
Participants	A total of 997 patients were included in analysis with 172 (17.2%) who were selectively cleared of immobilization per protocol
Test results	Sensitivity 90.9%, specificity 17.4%, PPV 2.4, NPV 98.8
Other information	
Funding	Not reported
QUADAS-2	
Patient selection	Patients with a blunt trauma and transported by emergency medical services suspected of cervical spine injury. Patients were excluded if they refused c-collar placement or if documentation was incomplete
Index test	Based on actual number of patients immobilized, not based on findings reported by EMS providers, leading to a high risk of bias
Reference standard	ICD-9 cervical spine injury was used as reference standard, which can lead to missing patients in case of miscoding
Flow and timing	Not all patients were included in the analysis, due to missing data (n=39) or refusal of c-collar placement (n=75); a total of 114 patients (10.3%) were missing

Abbreviations: NEXUS = National Emergency X-Radiography Utilization Study; EMS = emergency medical services; ICD-9 = International Statistical Classification of Diseases, ninth revision

Title	Value of prehospital assessment of spine fracture by paramedics
Authors	Ten Brinke JG, Gebbink WK, Pallada L, Saltzherr TP, Hogervorst M, Goslings JC
Year	2017
Methods	
Study design	Prospective cohort
Setting	One level II trauma center in Apeldoorn, the Netherlands
Participants	All patients with prehospital spine immobilization presenting at the emergency department
Test methods	Index test: before radiologic imaging, EMS providers recorded the probability of a spine fracture based on their own evaluation on a data collection form; they were asked to predict any spine fractures by answering 'yes' or 'no' Reference standard: the presence of a spine fracture was ruled out if computed tomography scanning was negative or if no clinical symptoms suggesting a spinal injury were detected during the 3-month follow-up period
Outcomes	Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), accuracy
Results	
Participants	190 patients presenting with prehospital spine immobilization; 139 of these patients were included in this study
Test results	Sensitivity 92%, specificity 30%, PPV 22%, NPV 95%, accuracy 41%
Other information	
Funding	None
QUADAS-2	
Patient selection	All trauma patients with spine immobilization based on the existing Dutch national immobilization protocol (LPA 7.2) were selected, possibly introducing selection bias. The patients were included if the EMS providers recorded the probability of a spine fracture based on their own evaluation on a data collection form before imaging
Index test	The index test was reported by the EMS providers in a standardized data questionnaire before radiologic imaging, leading to a low risk of bias
Reference standard	Radiologist reports of the radiographs were used as reference standard. Radiologists did not know the result of the index test. Patients without radiographs were assumed to have no spinal injury; these patients were checked during a 3-month follow-up period. This minimizes the chance of missed fractures and risk of bias
Flow and timing	Not all patients were diagnosed using the same reference standard; 51 (26.8%) patients were not included because of incomplete data forms

Abbreviations: EMS = emergency medical services

Title	The Out-of-Hospital Validation of the Canadian C-Spine Rule by Paramedics
Authors	Vaillancourt C, Stiell IG, Beaudoin T, Maloney J, Anton AR, Bradford P, Cain E, Travers A, Stempien M, Lees M, Munkley D, Battram E, Banek J, Wells GA
Year	2009
Methods	
Study design	Prospective cohort, validation study
Setting	7 Canadian regions, distributed in 3 Canadian provinces (Ontario, Alberta and Nova Scotia)
Participants	1,949 alert, stable, and cooperative patients transported by the EMS after blunt trauma
Test methods	Index test: Canadian C-Spine rule, reported on a standardized data collection form, including the interpretation of the rule (filled out before arrival at the hospital) Reference standard: some were diagnosed using radiographic imaging (plain radiography and CT). Those without radiographic imaging were contacted by telephone within 14 days to assess whether they had any spine-related complaints
Test performance	Sensitivity, specificity, kappa value for paramedic interpretation
Results	
Participants	Alert, stable and cooperative patients >16 years, transported by the EMS after blunt trauma
Test results	Sensitivity 100%, specificity 37.7%, kappa value for paramedic interpretation 0.93. Paramedics conservatively misinterpreted the rule in 16.4% and were comfortable applying the rule in 81.7%. 37.7% immobilizations could have been avoided had the Canadian C-Spine rule been used rather than the local protocol (not further specified)
Other information	
Funding	Not reported
QUADAS-2	
Patient selection	Only alert (Glasgow Coma Scale of 15), stable, and cooperative patients were included, possibly leading to selection bias, while many trauma patients will be excluded using these criteria
Index test	The paramedics completed training before using the rule and filled out a standardized form before arrival at the hospital, leading to a low risk of bias
Reference standard	Not all patients were diagnosed using the same reference standard
Flow and timing	Not all patients were included in the analysis, as not all patients could be reached by telephone for follow-up

Abbreviations: EMS = emergency medical services

CHAPTER 6

Secondary in-hospital immobilization in patients with suspected spinal injury: implications for treatment and outcome

J.G. ten Brinke, S.R. Groen, R. Detering, R.A.W. Meijer, T.P. Saltzherr, M. Hogervorst, J.C. Goslings

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Abstract

Introduction

In patients suspected of spinal-fractures arriving at the Emergency-Department (ED) without spinal-immobilization, the Advanced Trauma Life Support (ATLS) and European Trauma-Course (ETC) both advocate spinal-immobilization. However, introduction of pre-hospital spinal-immobilization protocol in the Netherlands (2016) led to discrepancies between protocol-recommendations applied in pre-hospital and in-hospital setting. We hypothesized this discrepancy is causing unnecessary immobilization of mobile and alert patients. Purpose of this study was to determine the proportion of non-immobilized patients suspected of spinal-fractures who are receiving secondary spinal-immobilization. Second, the incidence of spinal-fractures and effects of treatment-strategies on neurological outcome was determined.

Methods

Data was collected from all patients suspected for spinal-fractures presenting at the ED of a Dutch level-2 trauma-center between January 2010 and July 2012. Retrospectively data was analyzed from patients who had did not receive secondary-immobilization and patients who did. Measured outcomes were incidence of spinal-fractures, method of treatment-strategy and neurological outcome.

Results

Of 563 patients not receiving pre-hospital immobilization, 10% subsequently underwent secondary-immobilization at the ED. 87% of patients arriving without spinal-immobilization had not sustained a spinal-fracture. Incidence of spinal-fractures in patients receiving secondary-immobilization was 7% vs.12.8% in those not receiving secondary-immobilization. Three patients had neurological symptoms which were present in pre-hospital setting.

Conclusions

An high proportion of non-immobilized patients suspected of spinal injury are not receiving secondary in-hospital immobilization of the spine in our study. Additionally, a considerable proportion of patients arriving at the ED without spinal immobilization do have spinal-fractures. In three patients, symptoms of neurologic deficit were already present at ED arrival.

Introduction

The incidence of spinal injury in the United States is estimated at 2-6% of all trauma patients.[1] Approximately 10–30% of patients with spinal injuries have an unstable spinal fracture or damage to the spinal cord.[2-8] The overall incidence for Emergency Department (ED) visits due to spinal fractures is increasing.[7] If a patient is suspected of having a spinal injury, protocols of the international Advanced Trauma Life Support (ATLS), Pre-Hospital Trauma Life Support (PHTLS) and European Trauma Course (ETC) recommend precautions such as spinal immobilization until the spine has been cleared of injury.[9, 10] This clearance of the spine includes radiologic imaging or clinical decision rules such as the National Emergency X-Radiography Utilization Study (NEXUS)-criteria or the Canadian C-spine Rule (CCR).[11-13] The reason for spinal immobilization precautions is that unstable spinal injuries can deteriorate due to manipulation or movement, and cause secondary injury to the spinal cord.[14] Spinal immobilization protocols usually recommend the use of a rigid cervical collar and a spinal board.[1, 15-18]

Although spinal immobilization has become standard practice, to date no randomized controlled trials have been published on its effects.[19-21] In a retrospective chart review that evaluated the effects of spinal immobilization, Hauswald, et al. observed the incidence rate of neurological injury to be higher in an immobilized group than in a group without immobilization.[22] This study group concluded that spinal immobilization might not have any beneficial effect in preventing neurological injury after trauma. Since this study was published in 1998, several other groups have studied the benefits and drawbacks of spinal immobilization.[8] However, based on these results, no firm conclusions towards the use of spinal immobilization can be drawn.[21, 23, 24] While mentioned studies focused on spinal immobilization in the pre-hospital setting, we note that immobilization protocols may differ depending on the setting.

The Dutch emergency services are using a pre-hospital immobilization protocol, introduced in 2010 and updated in 2016.[25] This protocol (appendix A and B) dictates that ambulant and alert patients who can extract themselves from the trauma scene and who are able to lay down on a vacuum mattress or spinal board should be transported to hospital with head blocks but without a rigid collar.[26, 27] While this protocol is in accordance with recommendations in scientific literature, it has led to a discrepancy between the protocols currently used in the pre-hospital setting and those used in the in-hospital setting. The in-hospital protocol follows ATLS, PHTLS, and ETC guidelines, which all recommend full spinal immobilization including rigid collar and spinal board if a spinal injury is suspected. For patients presented at the ED without spinal immobilization, this implicates they potentially receive subsequently two kinds of treatment due to the clashing protocols. Usually these non-immobilized patients either present to the ED by self-referral or are not regarded by paramedics as being at risk of spinal injury upon on-scene evaluation. In literature there is only one study describing proportion of patients initially evaluated for spinal injury who subsequently are diagnosed with actual injury, which is in 2-3%.[28] In addition, spinal immobilization itself is not completely without harm and has several disadvantages. Several studies published spinal immobilization

to cause pressures sores, compromise respiration, necessitate aspiration after vomiting, raise intracranial pressure, and hamper airway management.[29-32] This raises the question upon the implications of the discrepancy between the pre-hospital and in-hospital protocols towards secondary immobilization at ED presentation in patients with suspected spinal injury in terms of treatment and neurological outcome.

The aim of this retrospective study was to determine the proportion of patients suspected of spinal injury who do in fact receive secondary in-hospital spinal immobilization at the ED of a Dutch level 2 trauma center. We also determined the incidence of spinal injuries and the effects of different treatment strategies on neurological outcome. To this end, we compared all patients diagnosed with a spinal fracture with those who did not receive secondary in-hospital spinal immobilization with patients who did.

Material and Methods

Design, Setting and Patient Characteristics

Data were retrospectively collected from all patients who were presented to the ED of a Dutch level 2 trauma center between 1 January 2010 and 1 July 2012. Patients were eligible for inclusion in our study if they had arrived at the ED without spinal immobilization and there was a clinical suspicion of spinal fracture. Patient characteristics were recorded, as well as the mechanism of injury, and the injury severity score was calculated (ISS).[33] Data from two separate groups of patients were compared: the first group had received no in-hospital immobilization (I-) until completion of the diagnostic process and the second group who had received secondary in-hospital immobilization (I+) upon arrival. For each group, we recorded the incidence of spinal fractures and neurologic deficits, and the types of treatment, if any. No ethical approval for this retrospective study was required under Dutch Law.

Data Analysis

All data were entered into an electronic database. We used descriptive outcome analysis to compare the outcomes of the two groups of patients who arrived at the ED without spinal immobilization and for whom there was clinical suspicion of spinal fracture. Data were described using means and standard deviations for normally distributed numerical data, medians and interquartile ranges for non-normally distributed numerical data, and numbers with percentages for categorical data. Normality of distribution was assessed visually by examining histograms. Differences between categorical variables were assessed by a chi-square-test or Fisher exact-test depending on expected frequencies, and between continuous variables by an unpaired t-test or Mann-Whitney U-test depending on distribution. A P-value of < 0.05 was considered statistically significant. Statistical analysis was performed using IBM® SPSS® for Windows® version 24 (IBM Corp., Armonk, NY, United States).

Theory/calculation

The aim of this retrospective study was to determine the proportion of patients suspected of spinal injury who do in fact receive secondary in-hospital spinal immobilization at the ED

of a Dutch level 2 trauma center. Primary outcome of this study was the incidence of spinal fractures in patients visiting the ED following trauma. Secondary outcomes were the method of definitive trauma care and neurological symptoms.

Results

Characteristics of Study Subjects

A total of 2,006 trauma patients presenting to the ED of our level 2 trauma center were retrospectively included in the database. Within this population, we selected the 563 patients (28.1%) presented to the ED without spinal immobilization. Of these patients, 57/563 (10%) had undergone secondary in-hospital immobilization (I+), while 506/563 (90%) patients remained without secondary in-hospital immobilization (I-) at the discretion of the treating physician on call at the ED. Spinal fractures where diagnosed in 69 patients, of which 65/69 (94%) did not receive secondary in-hospital immobilization (Figure 1). Of the included patients 50.9% was of male gender, the overall median age was 41.3±34.6 years (19-68). Presentation at the ED by self-referral was identified in 368/563 (65.4%) patients. A motor vehicle accident and a fall from heights lower than 2,5 meters were most common trauma mechanisms (Table 1).

Table 1. Baseline characteristics of patients presented at the ED without spinal immobilization.

		In-hospital immobilization		
		Yes (I+)	**No (I-)**	**P-value**
Total		57	506	
Sex	Male	29 (50.9%*)	257 (50.8%)	0.990
Age	median (IQR)	34 (19–60)	45 (22–68)	0.648
ISS	median (IQR)	5 (3–9)	4 (2–8)	0.058
Trauma				<0.001
	High-Energy Trauma (HET)	21 (36.8%)	76 (15.0%)	
	Multi-trauma (ISS ≥ 16)	1 (1.8%)	1 (0.2%)	
ED presentation by self-referral		32 (56.1%)	336 (66.4%)	<0.001
Mechanism of injury				<0.001
	Motor vehicle accident	23 (40.4%)	97 (19.2%)	
	Fall >2.5 meters	7 (12.3%)	42 (8.3%)	
	Fall <2.5 meters	12 (21.2%)	285 (56.3%)	
	Bike/person vs. car	1 (1.8%)	13 (2.6%)	
	Bike or horse accident	11 (19.3%)	45 (8.9%)	
	Fight or abuse	3 (5.3%)	21 (4.2%)	
	Parachute	0 (0.0%)	3 (0.6%)	
Fractures		4 (7.0%)	65 (12.8%)	0.203

*Percentages are within group; ISS: injury severity score; IQR: interquartile range.

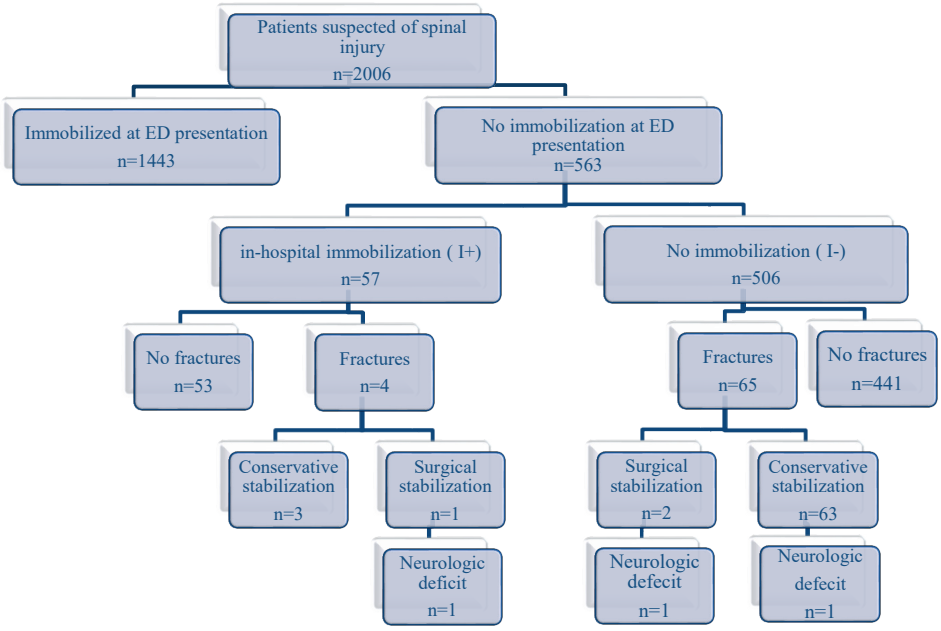

Figure 1. Flow diagram of patient inclusion and outcome parameters.

Endpoints

In 4/57 (7.0%) patients who had received secondary immobilization were subsequently found to have sustained a spinal fracture; one of them (1.8%) had neurological symptoms and required surgical stabilization (Table 2). This patient had presented to the ED with neurologic deficit in both legs and an unstable L3-fracture with spinal canal stenosis, four weeks after initial trauma. This patient was transferred to a level 1 trauma center, where a posterior spondylodesis was performed. The remaining three patients had no neurologic deficits and underwent non-invasive treatment as shown in Table 2. In the group of patients who had not received secondary in-hospital immobilization (I-), spinal fractures were identified in 65/506 (12.8%) patients. Two patients required stabilization using a halo frame (Table 2). Despite treatment, one of them developed rapidly progressive neurological symptoms and died. The other patient had no neurologic deficit and made a successful recovery. The other 63 patients diagnosed with a spinal fracture were treated conservatively (Table 2). One of them had permanent neurologic deficit but immobilization in this patient could not be applied due to morbid obesity. In all patients with neurological symptoms, the symptoms were already present prior to presentation to the ED.

Table 2. Types of spinal fractures and the different types of treatment applied.

		In-hospital immobilization		
		Yes (I+)	**No (I-)**	**P-value**
Total		57	506	
Location of fracture				0.382
	Cervical spine	0	5 (1.0%)	
	Thoracic spine	0	20 (4.0%)	
	Lumbar spine	4 (7.0%)	40 (7.9%)	
Type of fracture				0.967
	Body	4 (100%)	61 (93.8%)	
	Transverse process	0 (0.0%)	1 (1.5%)	
	Articular pillar	0 (14%)	2 (3.1%)	
	Spinous process	0 (0.0%)	1 (1.5%)	
Type of treatment				0.003
	Surgical stabilization	1 (1.8%)	0 (0.0%)	
	Conservative stabilization	56 (98.2%)	506 (100%)	
Conservative treatment				<0.001
	Collar	9 (16.1%)	4 (0.8%)	
	Spinal brace	3 (5.4%)	61 (12.1%)	
	Halo frame	0 (0.0%)	2 (0.4%)	
	Analgesia	44 (78.6%)	439 (86.8%)	

*Percentages are within-group

Discussion

The results of this study in patients presenting to the ED of a Dutch Level II trauma center indicates that a high proportion of non-immobilized patients suspected of a spinal fracture are not receiving secondary in-hospital immobilization of the spine. In addition, a considerable proportion of patients arriving at the ED without spinal immobilization do have spinal fractures. The incidence of spinal fractures in patients who underwent secondary in-hospital in immobilization 7% versus 12.8% to those who did not underwent secondary in-hospital immobilization at the ED. In three patients, symptoms of neurologic deficit present at ED arrival and was not deteriorated until after definitive treatment.

Even though the use of spinal immobilization has been questioned numerous times,[22,23,28,34] spinal immobilization in case of suspected spinal fracture remains standard practice in many hospitals, including our own. Despite clear protocols at our ED, implementing in-hospital immobilization is challenging. Although there is a discrepancy in the incidence of spinal fractures in patients without secondary in-hospital immobilization versus the group who did receive secondary in-hospital immobilization, it was not statistically significant. In 13% of patients not receiving secondary in-hospital immobilization a spinal fracture was diagnosed. Although there were no clear significant discrepancies in patient characteristics throughout both the immobilized and non-immobilized group, one could identify interesting correlations.

In addition, the median age of patients not secondary in-hospital immobilized seems higher than those actual receiving immobilization (34 vs. 45yrs, p=0.648). With referral to the severity of injury (ISS) and specific trauma mechanisms in both groups (Table 1), suggesting that there is a correlation of more severe injury in the group of patients receiving secondary in-hospital immobilization. In contrast, in both groups presentation at ED by self-referral was similar, but not significant.

Compared with the total number of patients who sustained a spinal fracture, the number of patients requiring invasive treatment was small. Our data indicate that most patients with a spinal fracture who arrive at the ED without spinal immobilization have sustained a fracture that is stable; they therefore receive conservative treatment. In our cohort, three of these patients required surgical stabilization, two of whom had sustained permanent neurological damage in the pre-hospital setting.

While previous studies have shown that it is difficult–if not impossible–to determine the moment during or after a traumatic injury at which patients sustain spinal cord damage, it is thought that it is most likely to have already occurred before immobilization.[22] In this study, for all patients who had symptoms of neurologic deficit, those symptoms were already present before presentation to the ED. In 3 patient's symptoms of neurologic deficit were identified, only one of them received secondary immobilization at the ED. There was no alleviation or aggravation encountered in the patients suffering neurologic deficit until after definite treatment, of which two patients received surgical stabilization. The numbers in this study confirm neurologic deficit to be present in pre-hospital setting and emphasize again the difficulty of adequate implementation of in-hospital immobilization.

One of the main limitations of this study is the relatively low number of patients included in this study who underwent secondary in-hospital immobilization, which may have affected the results of this study, although these numbers situate a reflection of daily practice. Future studies on this topic should cover a larger time period for including trauma patients in order to state more definite conclusions. The level of training and experience of the hospital staff, including physicians, paramedics and nurses, could have biased some of the results as well, particularly referring to protocol adherence and identifying those in need of in-hospital immobilization of the spine. Implementation of clear clinical decision rules or criteria within in-hospital protocols, including the ones provided by the NEXUS-criteria and CCR, is highly recommended. Several studies concluded spinal immobilization to may do more harm than good, cautioning its use referring to various adverse effects.[29-32] However, a vulnerable subgroup still exists in which the diagnosis may not be clinically apparent. We are of the opinion that any protocol that reduces the use of in-hospital immobilization of the spine needs to effectively safeguard this subgroup until they have been diagnosed, since secondary injury could bare serious consequences for the patient. We therefore recommend that physicians take appropriate precautions until a spinal fracture has either been diagnosed or excluded, and treated if required. In cases where symptoms persist, the patient should be reassessed. For this specific subgroup of vulnerable patients, we recommend maintaining a low threshold

for spinal immobilization, preferably achieved using head blocks only – if not already present – and no rigid collar according the Dutch Prehospital protocol.

Conclusions

A considerable proportion of patients arriving at the ED without spinal immobilization are later diagnosed with a spinal fracture. Neurologic deficit was present in three patients at ED presentation and did not deteriorate until after final treatment. Although the proportion of patients with a spinal fracture does not appear to differ between patients who receive secondary in-hospital immobilization and those who do not, a vulnerable subgroup remains in which diagnosis may not be clinically apparent. Maintaining a low threshold for spinal immobilization in this specific subgroup of vulnerable patients is recommended, preferably with minimal invasive measures. Future prospective studies are needed to obtain clear criteria for identifying those at need for secondary in-hospital immobilization of the spine.

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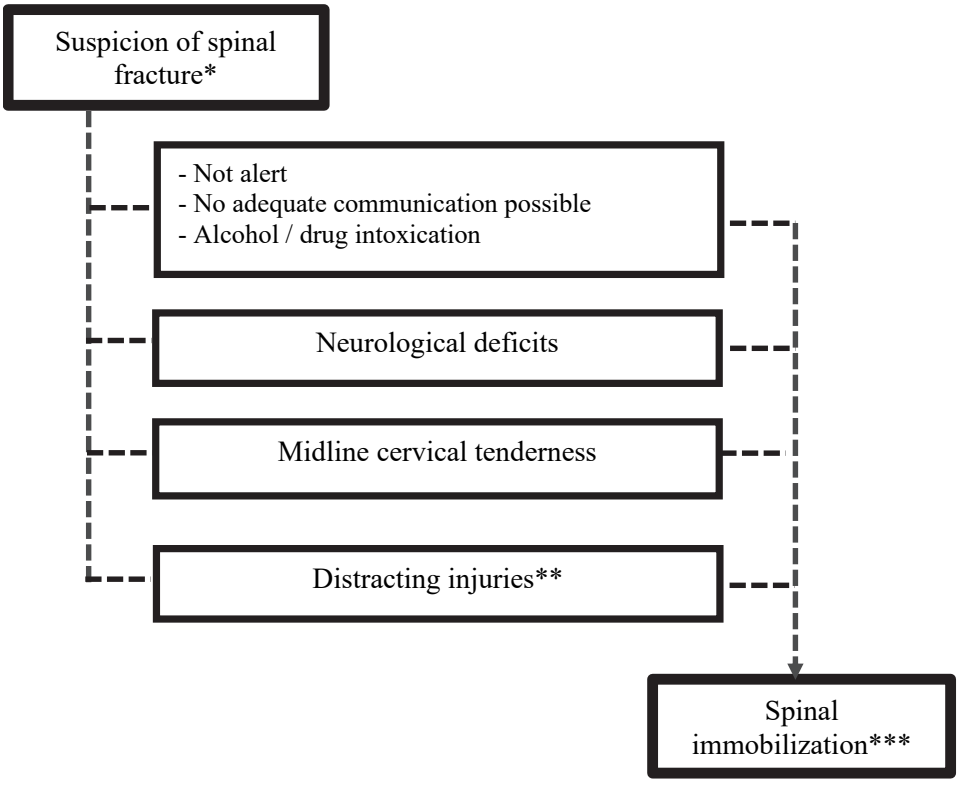
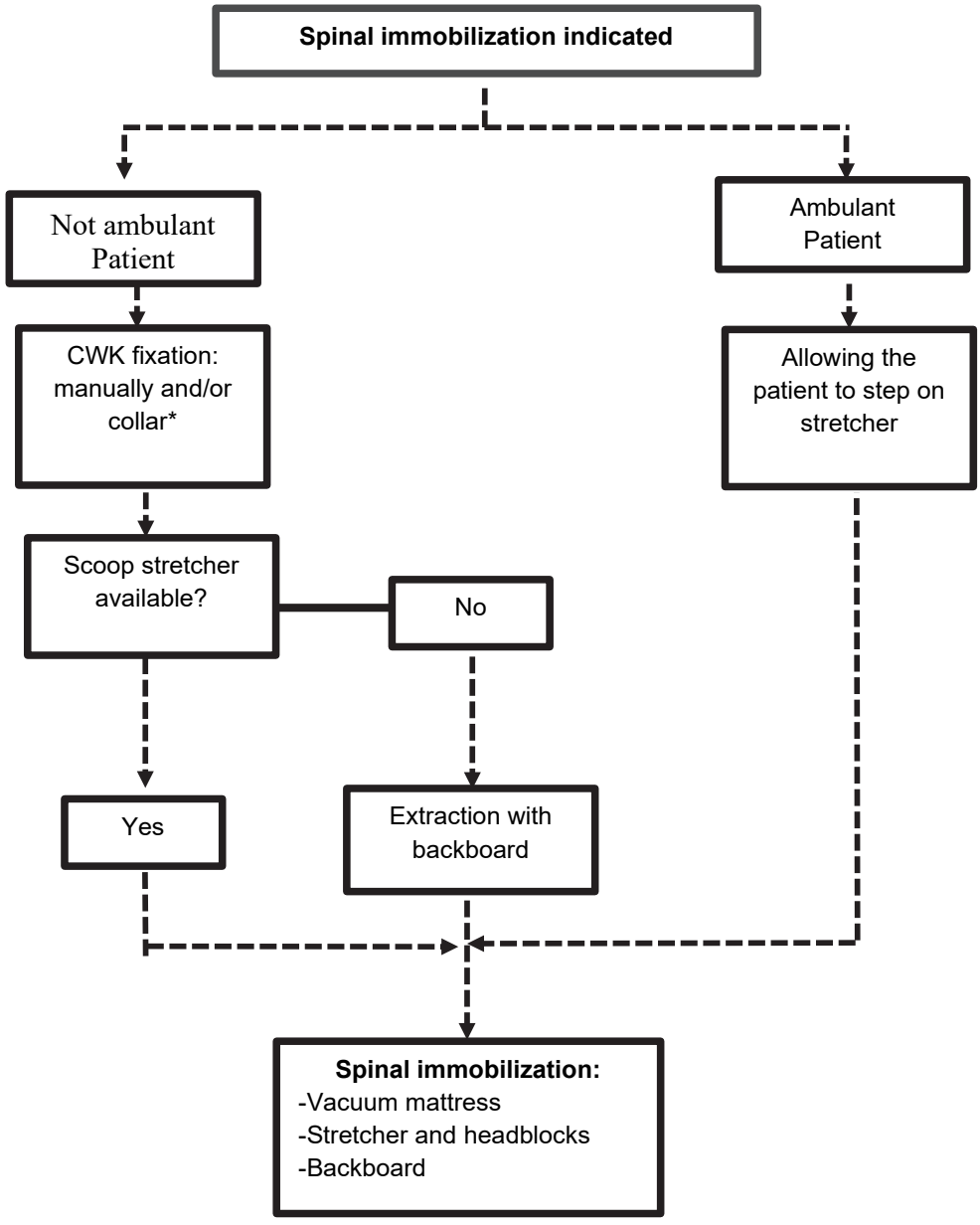
Appendix A. Indications for spinal immobilization.



* Every trauma mechanism with a chance of vertebral injury: in case of doubt immobilize
** Any painful injury that can cause spinal trauma to be missed
*** Immobilization may not lead to: delay of ABCD assessment; increased dyspnea, fear and / or anxiety

Immobilization is not necessary in case of:
penetrating injury of the head, CWK, thorax or abdomen without neurological failure

Appendix B. Flow-chart for spinal immobilization.



* Contra-indication collar: children and head/brain damage

CHAPTER 7

Increased and unjustified CT usage in paediatric C-spine clearance in a level 2 trauma centre

J.G. ten Brinke, G. Slinger, A. Slaar, T.P. Saltzherr, M. Hogervorst, J.C. Goslings

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Abstract

Purpose

Cervical spine injury after blunt trauma in children is rare but can have severe consequences. Clear protocols for diagnostic workup are therefore needed, but currently not available. As a step in developing such a protocol, we determined the incidence of cervical spine injury and the degree of protocol adherence at our level 2 trauma centre.

Methods

We analysed data from all patients aged <16 years suspected of cervical spine injury after blunt trauma who had presented to our hospital during two periods: January 2010 to June 2012, and January 2017 to June 2019. In the intervening period, the imaging protocol for diagnostic workup was updated. Outcomes were the incidence of cervical spine injury and protocol adherence in terms of the indication for imaging and the type of imaging.

Results

We included 170 children in the first study period and 83 in the second. One patient was diagnosed with cervical spine injury. Protocol adherence regarding the indication for imaging was >80% in both periods. Adherence regarding the imaging type decreased over time, with 45.8% of the patients receiving a primary CT scan in the second study period versus 2.9% in the first.

Conclusion

Radiographic imaging is frequently performed when clearing the paediatric cervical spine, although cervical spine injury is rare. Particularly CT scan usage has wrongly been emerging over time. Stricter adherence to current protocols could limit overuse of radiographic imaging, but ultimately there is a need for an accurate rule predicting which children really are at risk of injury.

Introduction

Paediatric patients suffering blunt trauma are always assessed for cervical spine injury (CSI) given the potential risk of morbidity and mortality.[1–3] However, CSI is rare, accounting for less than 2% of all children being evaluated in the after blunt trauma, even in higher risk populations presenting at level 1 trauma centres.[4–7] Identifying children at risk of CSI is challenging since physical examination can be unreliable.[8] In addition, trauma mechanisms in children differ from those in adults and are often associated with unique injury patterns, due to the anatomy of the paediatric cervical spine (C-spine).[5, 9, 10] When clearing the C-spine in children, radiographic imaging is often used, despite this being costly and exposing children to radiation and its associated risks. While CSI should not be missed, children at low risk of injury should not be subjected unnecessarily to radiation. If we had a validated clinical decision tool, we could better balance these conflicting interests and predict which children need radiographic imaging. Such a decision tool is, however, currently not available.[11]

In the adult population, the National Emergency X-Radiography Utilization Study (NEXUS) criteria and the Canadian C-spine Rule (CCR) have been extensively tested and validated (Tables 1 and 2).[12, 13] Analysis of these tools in children, however, is sparse. A 2017 meta-analysis concluded that the NEXUS criteria are at best a guide to clinical assessment, and not a strict protocol, while evidence for the accuracy of the CCR to detect CSI in the paediatric population is lacking.[14] Nevertheless, current international guidelines recommend combining both predicting rules.[11, 15, 16]

Table 1. Features of the NEXUS criteria

Midline tenderness of the C-spine
Focal neurologic deficit
Altered level of consciousness [A]
Evidence of intoxication
Distracting injuries [B]

C-spine: cervical spine; [A] Defined as a score of <15 on the Glasgow Coma Scale (GCS); [B] Including fractures of long bones, visceral injury, crush or laceration, burns.
Hoffman JR, Wolfson AB, Todd K, Mower WR. Selective Cervical Spine Radiography in Blunt Trauma: Methodology of the National Emergency X-Radiography Utilization Study (NEXUS). Ann Emerg Med. 1998 Oct;32(4):461–9.

Table 2. Features of the CCR

Age ≥ 65 years
Paresthesias in the extremities
Dangerous trauma mechanism (DTM)
Fall from ≥ 0.9 meters
Axial load injury (e.g. diving)
High speed motor vehicle accident (> 100 km/hr, rollover or ejection)
Bicycle collision
Accident with morotized recreational vehicle

Inability to actively rotate the neck >45°
Stiell IG, Wells GA, Vandemheen KL, Clement CM, Lesiuk H, De Maio VJ, et al. The Canadian C-spine rule for radiography in alert and stable trauma patients. JAMA. 2001 Oct 17;286(15):1841–8.

If CSI is suspected, various international trauma guidelines recommend plain radiography of the C-spine as primary imaging.[11, 16] Its sensitivity for detecting CSI is higher than 90%.[9, 11, 17–19] A CT scan of the C-spine is only indicated in those patients for whom a fracture is seen on plain radiography or for whom there is clinical suspicion of CSI despite a negative result with plain radiography.[20–22] A CT scan of the C-spine is the primary imaging modality exclusively in patients who are haemodynamically unstable or who have a reduced level of consciousness.[23, 24] The main reason for this is the increased risk of thyroid cancer: the relative risk from a CT scan is thought to be 13% to 25% higher than the risk from a plain radiograph,[21, 25, 26] except for low dose CT.

A first step towards developing a validated clinical decision rule is to determine the size of the problem and evaluate current practice. This is particularly crucial in low-risk populations, since radiographic imaging will have only minimal therapeutic yield in this group. We therefore analysed CSI clearance in our level 2 trauma centre during two periods, whereby our local protocol was updated and re-implemented in the intervening years. Our specific research questions were: I) What is the incidence of CSI in the paediatric population at our level 2 trauma centre? II) What is the degree of protocol adherence regarding when and what type of imaging should be requested?

Methods

Study design and population

We conducted a retrospective cohort study that included all children under the age of 16 presenting at the emergency department (ED) of a Dutch level 2 trauma centre and large teaching hospital with suspected CSI after blunt trauma, for whom radiography of the C-spine had been obtained. Two study periods were defined; one before and one after the re-implementation of the updated protocol in 2015. The first period (P1) was from January 2010 to June 2012 and the second period (P2) was from January 2017 to June 2019. Data were extracted from the computerized database of the hospital's radiology department and from electronic medical records.

Protocols and implementation strategy

The local trauma imaging protocol that was in use during P1 (Figure 1) had been established through a collaboration between the trauma and radiology departments of our hospital. It was designed for children under the age of 16 and stratified patients by age, discriminating between those up to the age of eight years and those aged nine and older. According to the protocol, radiographic imaging was required if patients had one or more of the high-risk features listed in the NEXUS criteria or if they had suffered trauma with a dangerous trauma mechanism (DTM), as listed in Table 2. The primary imaging modality was plain radiography. In children where plain radiography was inconclusive or where a fracture was seen, a CT scan of the Cspine was required. A CT scan of the Cspine was recommended as primary imaging modality for patients who had neurological symptoms or a Glasgow Coma Scale (GCS) below 13 at initial assessment.

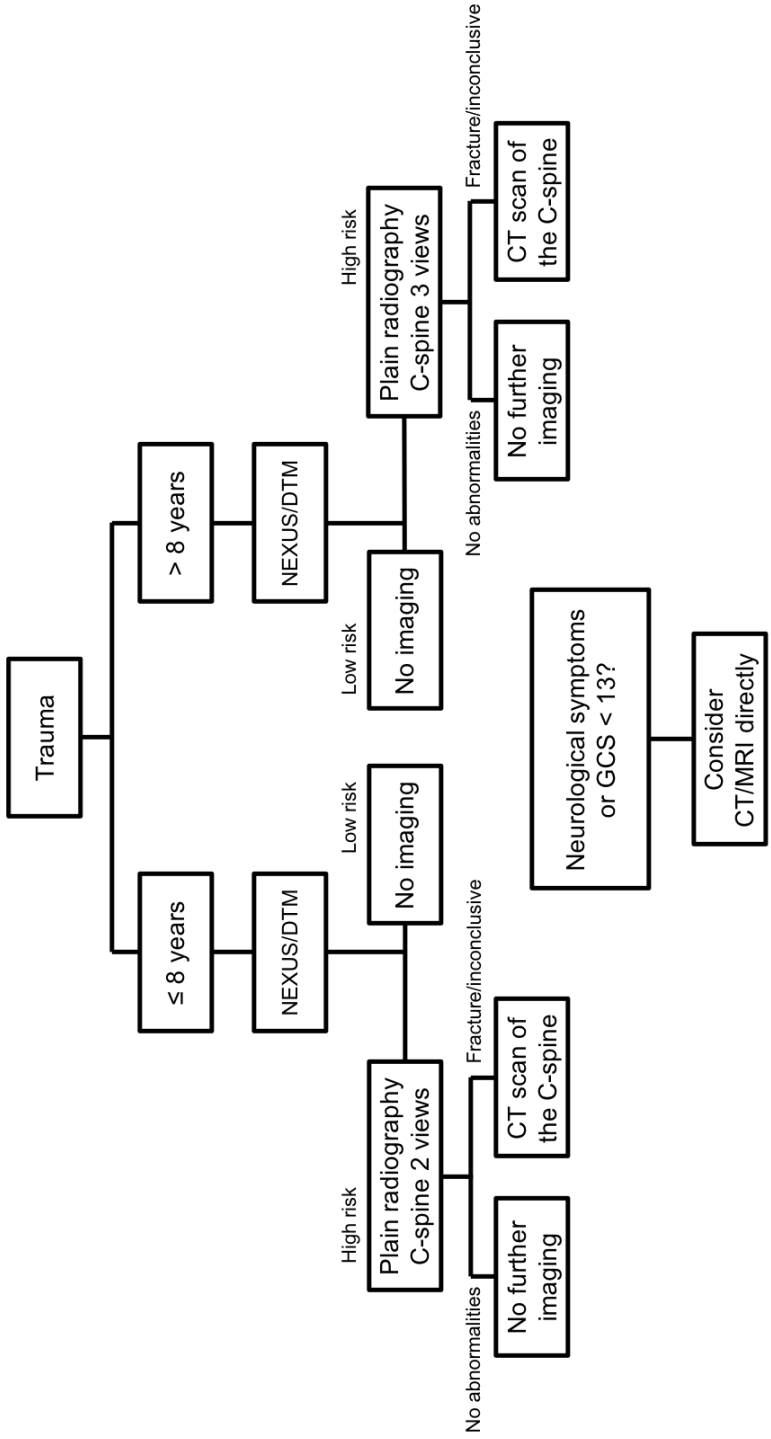

Figure 1. Flowchart of trauma imaging protocol used in study period 1, implemented in 2010
NEXUS: National Emergency X-Radiography Utilization Study; DTM: dangerous trauma mechanism; C-spine: cervical spine; GCS: Glasgow Coma Scale

The updated protocol (Figure 2) resembles the initial local protocol but only includes the NEXUS criteria. It also specifies that a CT scan should be used as the primary imaging modality for children who are haemodynamically unstable.

When implementing the updated protocol, we took account of factors previously reported to promote effective improvement of protocols in patients care. [27] In practice, this involved the following three components: (1) one trauma surgeon was responsible for preventing unnecessary imaging and for distributing the updated protocol; (2) all doctors and residents of the surgery, orthopaedic, and radiology departments at our hospital were informed about the protocol by e-mail and through presentations at in-hospital meetings; and (3) regional general practitioners were informed about the updated protocol, since we had noticed that they also frequently ordered imaging of the C-spine after trauma.

Definitions and outcome parameters

CSI was defined as any fracture or dislocation of the C-spine. CSI also included any neurologic deficit – comprising any new shortcoming in motor or sensory functioning – caused by blunt trauma of the C-spine. A DTM was defined in accordance with the CCR definition (Table 2).[13] We assessed the study populations from both periods for the following outcomes: incidence of CSI; frequency of plain radiography of the C-spine as primary imaging modality; frequency of CT of the C-spine as primary and as additional imaging modality; and adherence to the protocol with regard to (1) the indication for radiographic imaging and (2) the type of radiographic imaging.

Statistical analysis

All data were analysed with R statistical software version 3.5.3 (R Foundation for Statistical Computing, Vienna, Austria) using descriptive analyses. In accordance with the radiography protocols, we stratified the analyses in two age categories: (1) 8 years or younger and (2) 9 to 15 years.

Results

The 170 children in P1 had a mean age of 9.9 years. The mean injury severity score (ISS) was 5.7. In most patients, the trauma mechanism was a fall from height. The 83 children in P2 had a mean age of 11.5 years. The mean ISS was 2.4. Again, a fall from height was the most prevalent trauma mechanism. All patient characteristics are listed in Table 3.

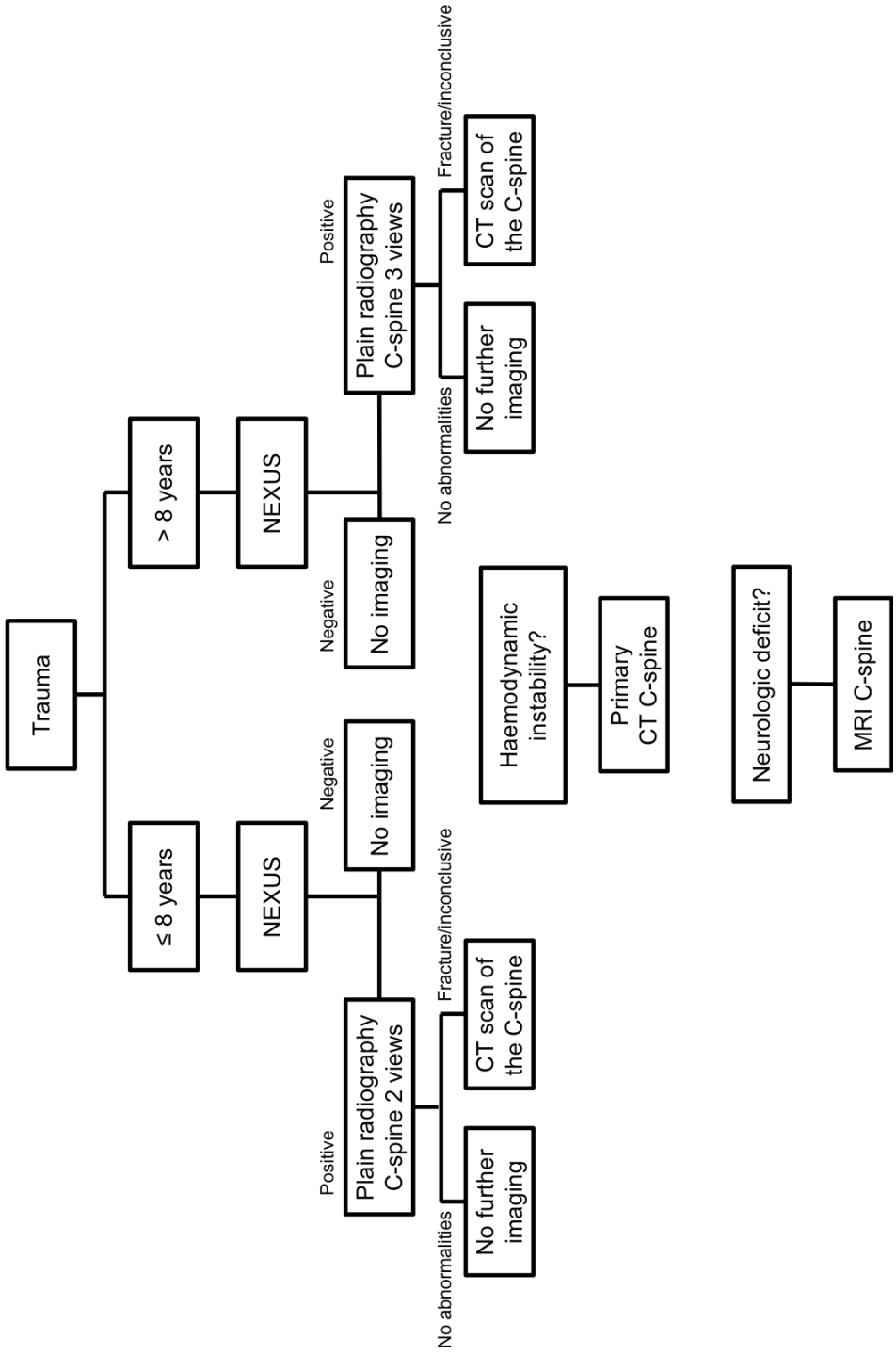

Figure 2. Flowchart of updated trauma imaging protocol used in study period 2, implemented in 2015
NEXUS: National Emergency X-Radiography Utilization Study; DTM: dangerous trauma mechanism; C-spine: cervical spine

Table 3. Baseline patient characteristics

	P1 (2010-2012)	P2 (2017-2019)
Total included, n	170	83
Male gender, n (%)	96 (56.5)	39 (47.0)
Mean age, yrs	9.88	11.5
Children ≤ 8 yrs, n (%)	53 (31.2)	17 (20.5)
Children > 8 yrs, n (%)	117 (68.8)	66 (79.5)
Hospitalised, n (%)	74 (43.5)	21 (25.3)
Mean duration of admission, days	2.16	2.14
Mean ISS, score (1-75)	5.67	2.43
Trauma mechanism		
Fall from height <2.5 meters, n (%)	44 (25.9)	40 (48.2)
Fall from height >2.5 meters, n (%)	45 (26.5)	5 (6.1)
Bike or horse accident, n (%)	37 (21.8)	18 (21.7)
Motor vehicle accident, n (%)	22 (12.9)	8 (9.6)
Bike of person versus car, n (%)	15 (8.8)	6 (7.2)
Person versus object, n (%)	7 (4.1)	6 (7.2)

n: number; yrs: years; ISS: Injury Severity Score

Table 4. Characteristics of the patient found to have cervical spine injury

Period	Age	Sex	MOI	ISS	NEXUS / DTM	Spine injury	Initial radiography	Treatment	Other injuries	Radiological FU
P2	13	F	Horse accident	5	+ / +	Ventral fracture body C5, ligaments intact	C-spine CT scan + subsequent MRI	Hard collar for 6 weeks	Excoriations extremities	3 C-spine X-rays

P2: study period 2; MOI: mechanism of injury; ISS: Injury Severity Score; NEXUS: National Emergency X-Radiography Utilization Study; DTM: dangerous trauma mechanism; FU: follow-up; C-spine: cervical spine; PT: psychical therapy

7

Incidence of CSI

In the first study period, no CSI was diagnosed after the initial work-up at the ED. Also, none of the patients were readmitted to our hospital with a missed injury. The incidence of CSI in P1 was therefore zero.

In the second study period, one patient was diagnosed with CSI: a fracture of vertebral body C5, without ligamentous injury. This patient was successfully treated with a hard collar for six weeks (Table 4). This one patient with CSI diagnosed gave an incidence in P2 of 1.2%. No CSI was missed at first presentation at the ED. For all patients taken together (P1 and P2), the incidence rate of CSI was 0.40%.

Radiography

In P1, a plain radiograph of the Cspine was the primary diagnostic imaging modality in 165/170 patients (97.1%). When we stratified the patients into groups based on age, the percentages of plain radiography as primary imaging modality were similar in the two age groups. A CT

scan of the C-spine was the primary diagnostic imaging modality in 5/170 patients (2.9%). An additional CT scan, after plain radiography, was performed in 22/165 patients (13.3%). All of those scans were without abnormalities. A higher proportion of additional CT scans was performed in children above the age of 8 (Table 5). No MRI scans were obtained, neither as primary nor as additional imaging modality.

In P2, plain radiography was the primary imaging modality in 45/83 patients (54.2%). The percentage of children undergoing plain radiography as primary imaging modality was higher in the group aged 8 or younger. A CT scan of the C-spine was the primary diagnostic imaging modality in 38/83 patients (45.8%), with a higher percentage in the group aged 9 and older as compared to the younger group (Table 5). Notably, we observed that many children underwent a combined CT scan of the C-spine and the brain; 72.4% of the children in whom we had obtained a CT scan of the brain received an initial CT scan of the cervical spine. This proportion was higher among the older children (Table 6). After plain radiography, an additional CT scan was performed in 3/45 patients (6.7%); all three scans were negative (Table 5). Overall, one MRI scan of the C-spine was obtained, which was found to be normal (patient characteristics described in Table 4).

Protocol adherence

Of the patients in P1, 152/170 (89.4%) met at least one of the NEXUS criteria or had a DTM, which means that they had an indication for radiographic imaging in accordance with the local protocol (Table 5). All of these children received the correct type of primary imaging according to the protocol, whether this was plain radiography or a CT scan. The remaining 18/170 patients (10.6%) were both NEXUS and DTM negative, and therefore retrospectively failed to meet one of the criteria for imaging. In this subgroup, no children received an initial or additional CT of the C-spine.

Of the patients in P2, 70/83 (84.3%) met at least one of the NEXUS criteria, thereby justifying radiographic imaging of the C-spine according to the updated protocol. Of all patients in this group, 39 (55.7%) had a primary plain radiography the C-spine and the remaining 31 (44.3%) underwent a primary CT scan. In all 31 children, the reason for an initial CT scan was unclear; one patient had a GCS below 13 but was not haemodynamically unstable. Despite 13/83 patients (15.7%) being NEXUS negative, they nevertheless underwent radiographic imaging. In more than half of them (7/13 patients, 53.8%) a primary CT scan of the C-spine was performed.

Table 5. Radiography and features meeting NEXUS criteria in study periods 1 and 2

	P1 (2010-2012)	P2 (2017-2019)
Radiography obtained in children ≤ 8 yrs, n (%)	53/170 (31.2)	17/83 (20.5)
Initial plain radiography (X-rays), n (%)	51/53 (96.2)	15/17 (88.2)
Additional CT scans, n (%)	2/51 (3.9)	1/15 (6.7)
Initial CT scans, n (%)	2/53 (3.8)	2/17 (11.8)
Radiography obtained in children > 8 yrs, n (%)	117/170 (68.8)	66/83 (79.5)
Initial plain radiography (X-rays), n (%)	114/117 (97.4)	30/66 (45.5)
Additional CT scans, n (%)	20/114 (17.5)	2/30 (6.7)
Initial CT scans, n (%)	3/117 (2.6)	36/66 (54.5)
Number of features on the NEXUS criteria		
0 features (NEXUS negative), n (%)	56/170 (32.9)	13/83 (15.7)
Presence of DTM, n (%)	38/56 (67.9)	- [A]
Absence of DTM, n (%)	18/56 (32.1)	- [A]
1 or more features (NEXUS positive), n (%)	114/170 (67.1)	70/83 (84.3)
1 feature, n (%)	89/114 (78.1)	58/70 (82.9)
2 features, n (%)	18/114 (15.8)	12/70 (17.1)
3 features, n (%)	7/114 (6.1)	0/70 (0)
4 features, n (%)	0/114 (0)	0/70 (0)
5 features, n (%)	0/114 (0)	0/70 (0)

n: number; yrs: years; NEXUS: National Emergency X-Radiography Utilization Study; DTM: dangerous trauma mechanism; a in the adapted protocol used in P2, DTM was no longer a criterion

Table 6. Initial CT scans of the cervical spine and CT scans of the brain in P2

	Primary CT C-spine (n)	CT brain (n)	CT brain + primary CT C-spine, n (%)
Children ≤ 8 yrs (n=17)	2	9	2 (22,2)
Children > 8 yrs (n=66)	36	20	19 (95,0)

n: number; yrs: years; C-spine: cervical spine
Example: of the 17 children aged 8 or younger, 2 had a primary CT scan of the cervical spine and 9 had a CT scan of the brain. 2 of the children with a CT scan of the brain underwent a primary CT scan of the C-spine (22.2%).

Discussion

While many children presenting at the ED after blunt trauma are suspected of CSI, the actual incidence is low. Adherence to both the initial and updated in-hospital protocol was high in terms of which children required imaging. However, in terms of the type of radiographic imaging requested for these children, adherence to the protocol was lower for the updated protocol than for the initial protocol, with much higher CT usage in the second study period.

As mentioned before, CSI incidence among children is low in our hospital, as only one patient with CSI was diagnosed during both study periods. These data correspond with the findings

of previous studies – performed both in level 1 trauma centres and other hospitals – which have also reported low incidences. The incidence varies from 0.3 to 3.7%, depending on the specific population studied.[4–7, 28] Our study confirms that a child presenting at a level 2 trauma centre after blunt trauma is very unlikely to have relevant C-spine injury.

With regard to the indication for imaging, adherence to our initial and updated in-hospital protocol was high. A study by Slaar *et al.* in a level 1 trauma centre also found that Dutch physicians generally do adhere to the guidelines in terms of which children require imaging.[4] Nevertheless, radiologic imaging could have been avoided in at least ten percent of our patients if the protocols had been followed in all cases. We note that there was a substantial difference in the size of the study groups in the two periods, with a reduction from 170 in P1 to 83 in P2. We postulate that the number of children undergoing radiographic imaging has nearly halved since implementing the updated protocol because physicians are adhering to it more strictly in terms of when imaging is mandatory. Other explanations might be a shift in injury severity, as the ISS and hospitalization rate were both lower in P2 than in P1. Another possibility is a decrease in the number of ED registrations, which we cannot rule out since we only included patients who underwent radiographic imaging. We consider these explanations unlikely, however, since the out-of-hospital protocols routing patients with suspected CSI did not change in the time between the two study periods.

In the second study period, a considerable number of patients underwent a primary CT scan without a clear indication. This increased use of CT imaging is an alarming but not isolated phenomenon. Since its introduction, CT usage in general has grown massively, both in adults and in the paediatric population, especially in emergency settings.[29–32] In the paediatric ED, a CT of the brain is by far the most commonly performed CT examination; the largest increase, however, has been reported for CT scans of the cervical spine and chest.[32, 33] And although some studies report that the total volume of CT utilization in children seems to have declined over the last decade – possibly due to the widespread introduction of clinical decision tools [26, 31, 34] – others still report a stable, increased or unexpectedly high CT utilization rate in children suffering blunt trauma.[28, 35] This suggests that protocols are still not being sufficiently implemented in daily practice, or that concurrent developments are hindering physicians' adherence to these protocols. In this regard, it is possible that our strategy for re-implementing an updated version of the protocol was inadequate, but this is unlikely to fully explain the increase in CT utilization between P1 and P2, since nearly all primary CT scans performed in P2 would also not have been justified under the previous protocol used in P1. It seems more likely that the protocol in our hospital for brain scanning is largely responsible, since the majority of children, particularly the older ones, who underwent a CT scan of the brain also had a CT scan of the C-spine as primary imaging modality. Combining imaging of the brain and spine in a single radiographic examination might be time efficient but cannot be justified. Furthermore, many physicians still underestimate the amount of radiation exposure due to CT imaging and the associated cancer risks, as shown by previous studies.[36–40] This underestimation might be resulting in physicians using adult standards in the diagnostic work-up of trauma in older children.

This study has a number of limitations. A retrospective study design is inherently associated with the risks of information bias and selection bias. A second limitation is that we evaluated protocol adherence in a level 2 trauma centre, while patients with more severe trauma and a higher chance of CSI are more likely to present to level 1 centres. However, evaluation of CSI clearance in level 2 centres is nevertheless relevant, especially given the apparent overuse of radiographic imaging in a population that has relatively mild trauma and therefore a relatively low risk of CSI. A third limitation lies in the fact that we only included patients who had undergone radiographic imaging, which means that we might have missed patients who had CSI but did not undergo radiographic imaging. Consequently, we cannot know whether or not these patients met one of the imaging criteria and might have overestimated protocol adherence regarding which children required imaging. To rule out any such missed injuries, we actively searched for secondary hospital visits in patients records. However, we did not monitor follow-up visits at other hospitals, so we may have underestimated the incidence of CSI at our hospital.

This study shows daily practice and adherence to imaging protocols. It also illustrates the need for developing and validating a clinical decision tool for clearing the C-spine of injury in children. Since evidence for the application of the NEXUS criteria in the paediatric population is sparse, there is a need for prospective research to evaluate its diagnostic accuracy or to find other predictors of CSI. The need for such research is particularly highlighted by our observation that many children suffering blunt trauma are NEXUS positive, while only a minority of them has CSI. This means that, under the current protocol, even 100% adherence leads to radiographic overuse. Given the current level of evidence, we respectfully disagree with Hale et al. who have recommended primary CT imaging in the evaluation of suspected CSI in children, even when taking into account that they studied a level 1 trauma centre population.[41] CT usage in the paediatric population should be avoided where possible to limit its adverse effects and unnecessary health care costs. The advent of low-dose CT might change this perspective, but until its widespread availability CT use should to be minimized. We also recommend that a combined CT scan of the C-spine and the brain for convenience purposes should meet strict criteria. In order to limit the use of CT imaging, it is important that all physicians are aware of its risks and strict indications. A helpful instrument in improving such awareness is adding a list of imaging criteria as checkboxes to the current CT application form.

Conclusion

CSI after blunt trauma in a paediatric population of a level 2 trauma centre is rare. Our observation of an increase in CT usage over time – usage that is not in accordance with the local protocol – indicates that improving the benefit-to-risk ratio in the evaluation of cervical spine injury requires stricter adherence to the current protocol. Future studies focused on the development and validation of a better clearance and strategies for adherence are needed in order to further reduce the risk side of this ratio.

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CHAPTER 8

Summary

Summary

This thesis focuses on three topics: the incidence of spinal injuries in the Netherlands, the effectiveness of spinal immobilization procedures, and the diagnostic work up of spinal injuries in children. These topics are addressed by answering the following research questions:

1. What are the incidence rates of spinal injuries in the Netherlands?
2. Can spinal immobilization be explained historically?
3. How accurately can paramedics predict the presence of a spinal fracture?
4. What is the most accurate and best analysed pre-hospital spinal immobilization protocol for identifying trauma patients with a spinal injury in need of immobilization?
5. What is the impact of secondary in-hospital immobilization?
6. What is the incidence of spinal injury in children and what is the level of protocol adherence regarding imaging of the spine?

These research questions are addressed in Chapters 2-7.

Chapter 2 in this epidemiological study, the Dutch Injury Surveillance System (LIS) was used to determine trends in the number of Emergency Department (ED) visits, hospital admission rates, number of spinal cord injuries and patient characteristics related to spinal fractures in the period from 1997-2012. In this 15-year period, a total of 95,933 ED visitors were diagnosed with a spinal fracture. The overall incidence rate for ED visits due to spinal fractures increased from 27 to 58 per 100,000 persons. This increase was seen in all age groups with a higher increase in older people. While hospital admissions due to spinal fractures increased with the increase in diagnosis (from 17 to 35 per 100,000 persons), the numbers of spinal cord lesions remained stable (14 to 15 per 1,000,000 persons).

The diagnosis and treatment of suspected spinal injuries is a cumbersome procedure and there is some disagreement in the field about the necessity of immobilization for all patients. Current global guidelines recommend that trauma patients with suspected spinal injuries need to be immobilized to reduce the risk of neurological deterioration.[1-4] However, the scientific basis for this precautionary measure is poor.[5, 6] In addition, many patients are immobilized unnecessarily and spinal immobilization itself can cause severe side effects.[5, 7-9] It is therefore relevant to unravel the historical origin and development of spinal immobilization.

As the historical review in **Chapter 3** demonstrates, the history of treating spinal injuries essentially dates back to prehistoric times.[10-13] Descriptions of pre-hospital spinal immobilization are more recent and span two distinct periods. First documentation of its use comes from the early 19th century, when pre-hospital trauma care was introduced on the battlefields of the Napoleonic wars.[14] In recent decades, adoption of Advanced Trauma Life Support (ATLS)[15] has elevated in-hospital trauma care to a high standard. The practice of spinal immobilization in the case of a suspected injury in a in-hospital setting has also been implemented as standard care in the pre-hospital setting.[16, 17] Although widely implemented, spinal immobilization in patients after blunt trauma cannot be explained historically, nor is there any high-level

scientific evidence to support or reject it.[5-7, 18-20] The current situation appears to have reached a deadlock.

Striking an appropriate balance between the benefits of spinal immobilization on the one hand and its harms on the other requires identifying the most accurate immobilization criteria currently in use and potentially developing new criteria. Since previous studies have shown that emergency medical services (EMS) providers can accurately predict injury severity,[21, 22] incorporating their expert judgement into the immobilization criteria in pre-hospital settings would likely be beneficial. This could mean a step forward in preventing unnecessary immobilization. **Chapter 4** focuses on the potential ability of paramedics to predict spinal fractures. Over a one-year period, 139 patients were included in a prospective cohort. Prior to the diagnosis, EMS providers recorded the probability of a spinal fracture after a prehospital examination. These predictions were compared with patient outcomes. Paramedics could predict the presence of a spinal fracture with an accuracy of 41%., This relatively low degree of accuracy suggests that implementation of a protocol based solely on paramedics' predictions will not substantially reduce the overuse of spinal immobilization.

Chapter 5 analyses the pre-hospital spinal immobilization protocols in a systematic review that aimed to identify the most reliable and accurate protocol in trauma patients with a spine injury in need of immobilization. Our extensive literature search resulted in 11 studies eligible for qualitative synthesis. A critical appraisal of the included studies demonstrated that most studies were of poor quality. Nine different spinal immobilization protocols were analysed, most with similar criteria. Protocol-based and immobilization-based quality analysis showed high sensitivity and low specificity, resulting in moderate accuracy for most protocols. As a result, no single protocol stood out as being better than the rest.

The Dutch EMS use a pre-hospital immobilization protocol that was introduced in 2010 and updated in 2016.2[3, 24] While this protocol is in accordance with recommendations from the scientific literature, it has led to a discrepancy with the protocol currently used in the in-hospital setting, which follows the guidelines of the ATLS training programme.[15] This means that patients with a suspected spinal injury presenting at the ED without spinal immobilization can potentially receive two different types of treatment, one after the other. However, it was not known how frequently this happens and what the consequences are. The retrospective cohort study in **Chapter 6** describes the numbers of patients suspected of spinal injury who do in fact receive secondary in-hospital spinal immobilization at the ED. Of 563 patients who did not receive pre-hospital immobilization but who were suspected of spinal injury at the ED, 10% subsequently underwent secondary in-hospital immobilization. The incidence of spinal fractures in the group of patients who received secondary immobilization was in fact lower than in the group who did not (7% vs. 12%).

While the detection of spinal injuries in adults usually follows current trauma guidelines, evidence in the literature regarding the application of these guidelines to children is lacking. **Chapter 7** deals with protocol adherence and specifically the timing and the type of imaging

performed in children suspected of spinal injury. We analysed data from all patients aged < 16 who were suspected of cervical spine injury after blunt trauma and who had presented to our hospital during two periods: January 2010 to June 2012, and January 2017 to June 2019. In the intervening period, the imaging protocol for diagnostic workup was updated. We included 170 children in the first study period and 83 in the second. One patient in the total group was diagnosed with cervical spine injury. Protocol adherence regarding the indication for imaging was > 80% in both periods. However, adherence regarding the imaging type decreased over time, with the proportion of patients receiving a primary CT scan rising from 2.9% to 45.8%. Although the guidelines on imaging of the cervical spine in the paediatric population are clear, computed tomography (CT) usage in general has increased considerably since its introduction for both adults and children, especially at the ED.[26,25] This is a cause for concern given the potential increases in children's lifelong risk of cancer due to the radiation used in this type of imaging.

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CHAPTER 9

General discussion and future perspectives

Discussion

The estimated incidence of spinal injuries is 2–6% of all polytrauma patients.[1, 2] Approximately 10–30% of patients with spinal injuries have an unstable spinal fracture and only a minority have damage to the spinal cord.[3-5] Such injuries have a major impact on society given the low functional outcomes and the low return-to-work rates.[6] This impact is also reflected in the management and treatment of patients suspected of spinal injuries. Healthcare workers in both the pre-hospital and in-hospital setting are trained to take rigorous precautionary measures and follow strict protocols to rule out a potential injury. However, the majority of trauma patients do not have a spinal injury, meaning that for many patients these measures are unnecessary. In addition, scientific evidence for the efficacy of these measures are scarce or absent, and the measures themselves are not without harmful adverse effects.[7-11] Given the impact on society and patient health as well, it is crucial to understand the magnitude of the problem and to scrutinize the scientific basis of the current precautionary measures and protocols.

This thesis focused on the following three topics:

- The incidence of spinal injuries in the Netherlands
- The effectiveness of spinal immobilization procedures
- The diagnostic work-up of spinal injuries in children

The incidence of spinal injuries in the Netherlands

The epidemiology study in **Chapter 2** describes the magnitude of spinal injuries in the Netherlands over a 15-year period. During this period, the absolute number of patients who were diagnosed with a spinal fracture more than doubled, and this increase was observed independently of age and gender. The Dutch Injury Surveillance System (LIS) used in this study only provides numbers on outcome measures, which unfortunately hinders the analysis of any causal mechanisms underlying the observed trends. The biggest increase in spinal fractures was seen in the age group above 55 years (145%). This would be expected due to increasing life expectancy and the associated number of osteoporotic individuals in the population.[12-14] While the largest increase was observed in the older population, the rise in spinal fractures was seen in all age groups. A possible explanation for this observed rise is the increased use of computed tomography (CT) scans. Since its introduction, CT usage in general has grown immensely, especially in emergency settings.[15-17] This could have led to a considerable increase in the numbers of spinal fractures identified.

The effectiveness of spinal immobilization procedures

The diagnosis and treatment of suspected spinal injuries is a difficult process and experts in the field disagree on the appropriateness of immobilization. The current standard in the pre-hospital care of trauma patients suspected of spinal injury is to immobilize the spine to prevent secondary spinal cord injury. Spinal cord injuries are dynamic: some deteriorate due to microvascular injury and swelling, while some improve over time. Faced with these uncertainties and substantial medicolegal pressure, doctors worldwide have incorporated the

treatment of immobilization of the spine (**Chapter 3**). This treatment although mechanically intuitive is not proven entirely beneficial. Firstly, scientific evidence that supports this treatment is sparse. Secondly, there is also an obvious downside to this treatment strategy: immobilization takes time, delays transport to the hospital, is uncomfortable, and has adverse effects including respiratory compromise, neck and back pain, and pressure sores.[18-21] And the question remains: in which patients will motion make the spinal cord lesion worse?

Several factors make it difficult or even impossible to investigate whether pre-hospital immobilization prevents secondary spinal cord injury. These factors include the relatively low incidence of spinal cord injury (**Chapter 2**), healthcare workers' fear of missing or introducing an iatrogenic spinal cord lesion, ethical concerns related to randomization of patients in a pre-hospital setting suspected of spinal injury, and the lack of a validated pre-hospital neurological examination. Until now, research on spinal immobilization has focused on spinal injuries in general.

A significant way of improving current national pre-hospital practice could be to treat patients with suspected spinal injuries with as much restraint as possible in order to minize the adverse effects of immobilization. In this respect, progress was made in 2016 with the introduction of an update to the pre-hospital immobilization protocol used by the Dutch medical services. This protocol dictates that ambulant and alert patients who can extract themselves from the trauma scene and who are able to lie themselves down on a vacuum mattress should be transported to a hospital with only head blocks, a protocol that is in accordance with the sparse scientific literature.[22, 23] However, this pre-hospital protocol has led to a difference between the protocol currently used in the pre-hospital setting and that used in the in-hospital setting. This implies that these patients with suspected spine injuries can potentially receive two kinds of treatment due to the two different protocols (**Chapter 6**). The immobilization protocols used internationally are based on the Pre-Hospital Trauma Life Support (PHTLS) and Advanced Trauma Life Support (ATLS) guidelines.[24, 25] These guidelines still recommend the combination of a rigid collar with head blocks strapped to a spine board, despite international awareness of the potential risk of this combination. Taken together with the adage of the founder of the ATLS who stated that "if there is something wrong with the system, the system has to be changed", this therefore suggests the use of a single universal protocol that is safe and that has as few adverse effects as possible.

The results of the systematic review (**Chapter 5**) have shown that current worldwide pre-hospital immobilization protocols have high sensitivity but low specificity, resulting in only moderate accuracy (**Chapter 5**). Since the success of an immobilization protocol relies on the interpretation and compliance of paramedics, we studied the ability of paramedics to predict the presence of a spinal fracture in trauma patients (**Chapter 4**). While the results of this study indicated that paramedics can predict the presence of a spinal fracture with a relatively low accuracy (41%), no distinction was made between stable and non-stable fractures. To be useful, a spinal immobilization protocol must identify patients with significant spine injuries that may require stabilization of the spine. So future research should focus on

unstable fractures with a chance of spinal cord injury. Prediction by paramedics can still be a useful tool to reduce the number of patients who are immobilized.

Despite efforts in the pre-hospital setting to apply spinal immobilization correctly, a considerable proportion of patients arriving at the ED without spinal immobilization do have spinal fractures (**Chapter 6**). As stated earlier, the supporting and opposing evidence regarding spinal immobilization is equally divided. However, a solution to this dilemma is much needed given the possibly devastating results of not immobilizing patients with a spinal injury on the one hand, and unnecessary immobilization and its consequences on the other. Given the existence of a vulnerable subgroup in which the diagnosis may not be clinically apparent (e.g. in unconscious patients), any protocol that reduces the use of spinal immobilization of the spine needs to effectively safeguard this subgroup until they have been diagnosed. Consequently, maintaining a low threshold for spinal immobilization is recommended in this subgroup, though immobilization should preferably be through the use of head blocks only and no rigid collar as in the Dutch pre-hospital protocol.

The diagnostic work-up of spinal injuries in children

The incidence of cervical spinal injury (CSI) in children is low and adherence to the in-hospital imaging protocol in our hospital is high (**Chapter 7**). Despite the fact that various international trauma guidelines recommend plain radiography of the cervical spine as the primary imaging modality in children, [26-28] the usage of CT scans has increased (**Chapter 7**). This trend of increasing use of CT scans in children suspected of CSI is not an isolated phenomenon however, as the use of CT in general has grown in emergency settings.[15-17] However, Hippocrates' dictum "Primum non nocere" also applies to the use of the CT scan in children suspected of CSI. The relative risk of thyroid cancer from a CT scan of the cervical spine compared with a plain radiograph is thought to be 13–25%.[29, 30] Therefore, the recommendation that CT imaging should be the primary imaging modality in the evaluation of suspected CSI in children cannot be supported.[31] CT usage in children should be "As Low As Reasonably Achievable" (ALARA) to limit its adverse effects and unnecessary health care costs.

Future perspectives

The incidence of spinal injuries in the Netherlands

In this thesis I describe the growing problem of an increase in spinal fractures in the Netherlands, particularly in the elderly. To reduce the incidence of spinal fractures in the older population, it is pivotal for public health policy to focus on preventive measures such as osteoporosis treatment and fall prevention. Furthermore, future research should explore the potential causal mechanisms in the groups in which we are seeing the greatest increase in spinal fractures and look further into ways of reversing this rise.

The effectiveness of spinal immobilization procedures

Unfortunately, the key question of this thesis, i.e. whether pre-hospital immobilization can achieve its primary goal of preventing spinal cord injury, remains largely unanswered and is

unlikely to be resolved in the near future. This is because effective investigation of the effect of pre-hospital immobilization is complicated by several factors. These include the low incidence of spinal cord injuries, healthcare workers' fear of missing or introducing an iatrogenic spinal cord lesion, ethical concerns related to randomization of patients in a pre-hospital setting suspected of spinal injury, and the lack of a validated pre-hospital neurological examination. For that reason, we will continue to be confronted with a group of trauma patients that has been immobilized without a valid reason.

Despite this, there are ways to significantly improve the current situation, the main one being to minimize the number of patients who are immobilized. Future research should therefore focus on the group of patients who might have an unstable spinal fracture, because these are the patients who will potentially benefit from spinal immobilization. Only with large multi-centre studies or long-lasting registries will it become possible to generate the data required to study the effect of immobilization on the unstable spine. This might result in a more tailor-made protocol that is sufficiently specific such that only patients with a clinically relevant fracture are immobilized.

Another way to improve current practice is to treat patients with suspected spinal injuries with as much restraint as possible. Nowadays, roofs are still being ripped off cars to extricate patients with possible spinal injury and patients are transported to hospitals with a rigid collar and head blocks strapped to a spine board, despite the known risks of such action. The adoption by international organizations such as ATLS and PTHLS of the Dutch pre-hospital immobilization protocol would not only reduce the risks associated with immobilization, but also increase patient comfort and save precious time for pre-hospital medical services. Also the effects of this newly adopted protocol need to be monitored so that we don't end up in the same situation we're in now.

The diagnostic work-up of spinal injuries in children

As a final note on the diagnostic work-up of suspected spinal injuries in children, future research in this field should focus on developing and validating a clinical decision tool for "clearing" the cervical spine in children. Such a tool is required to better predict which children need radiographic imaging, as the decision tools currently in use have been validated on adults. Until the widespread introduction of new low-dose CT scanners, the primary imaging modality in children should be plain radiography of the C-spine to reduce the risk of radiation.

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NEDERLANDSE SAMENVATTING

Samenvatting

Dit proefschrift richt zich op drie onderwerpen: de incidentie van wervelkolom letsels in Nederland, de effectiviteit van wervelkolom immobilisatie procedures, en het diagnostische proces van wervelkolom letsels bij kinderen. Deze onderwerpen worden uiteengezet door de volgende onderzoeksvragen te beantwoorden:

1. Wat zijn de incidentiecijfers van wervelkolom letsels in Nederland?
2. Is wervelkolom immobilisatie historisch te verklaren?
3. Hoe accuraat kunnen ambulance medewerkers de aanwezigheid van een wervelkolomfractuur voorspellen?
4. Wat is het meest accurate en best geanalyseerde pre-hospitale immobilisatie protocol voor het identificeren wervelkolom letsel in trauma patiënten die immobilisatie nodig hebben?
5. Wat is de impact van secundaire immobilisatie in het ziekenhuis?
6. Wat is de incidentie van wervelkolomletsel bij kinderen en wat is de mate van protocolnaleving met betrekking tot beeldvorming van de wervelkolom?

Deze onderzoeksvragen worden behandeld in hoofdstuk 2-7.

Hoofdstuk 2 in deze epidemiologische studie werd het Nederlandse Letsel Informatie Systeem (LIS) gebruikt om trends vast te stellen in aantal bezoeken aan de spoedeisende hulp (SEH), ziekenhuisopnamecijfers, het aantal ruggenmergletsels en patiëntkenmerken gerelateerd aan wervelkolomfracturen in de periode van 1997-2012. In deze 15-jarige periode werden in totaal 95.933 SEH-bezoekers gediagnosticeerd met een wervelkolomfractuur. De totale incidentie van SEH bezoeken als gevolg van wervelkolomfracturen steeg van 27 naar 58 per 100.000 personen. Deze stijging werd waargenomen in alle leeftijdsgroepen met een grotere stijging bij ouderen. De toename van ziekenhuisopnames ten gevolge van wervelkolomfractuur opnamen stegen gelijkmatig met de stijging van de diagnose wervelkolomfracturen (van 17 tot 35 per 100.000 personen). Het aantal ruggenmergletsels bleef stabiel (14 tot 15 per 1.000.000 personen).

De diagnose en behandeling van wervelkolom letsels is een complexe procedure en er bestaat onenigheid over de noodzaak van wervelkolom immobilisatie voor alle patiënten die worden verdachten van wervelkolom letsel. De huidige wereldwijde richtlijnen raden aan dat traumapatiënten die worden verdacht van wervelkolom letsel moeten worden geïmmobiliseerd om het risico van secundaire neurologische schade te reduceren.[1-4] De wetenschappelijke basis voor deze voorzorgsmaatregel is echter matig.[5, 6] Bovendien worden veel patiënten onnodig geïmmobiliseerd en kan wervelkolom immobilisatie zelf ernstige bijwerkingen veroorzaken.[5, 7-9] Het is daarom belangrijk om de historische oorsprong en ontwikkeling van spinale immobilisatie te ontrafelen.

Zoals het historische overzicht in **hoofdstuk 3** laat zien, gaat de geschiedenis van de behandeling van wervelkolomletsels terug tot de prehistorie.[10-13] Beschrijvingen van pre-

hospitale immobilisatie van de wervelkolom zijn recenter en bestrijken twee verschillende periodes. De eerste documentatie over het gebruik ervan stamt uit het begin van de 19e eeuw, toen pre-hospitale traumazorg werd geïntroduceerd op de slagvelden van de Napoleontische oorlogen.[14] In de laatste decennia heeft de invoering van Advanced Trauma Life Support (ATLS)[15] de ziekenhuis traumazorg tot een hoge standaard verheven. De praktijk van wervelkolom immobilisatie in een ziekenhuis is ook geïmplementeerd als standaard zorg in de pre-hospitale setting.[16, 17] Hoewel wijdverbreid geïmplementeerd, kan wervelkolom immobilisatie bij patiënten na een stomp trauma niet historisch worden verklaard, noch is er enig wetenschappelijk bewijs van hoog niveau om het te ondersteunen of te verwerpen.[5-7, 18-20] De huidige situatie lijkt in een impasse te zijn geraakt.

Om een goed evenwicht te vinden tussen de voordelen van immobilisatie van de wervelkolom enerzijds en de nadelen ervan anderzijds vereist ontwikkeling van nauwkeurige immobilisatiecriteria. Aangezien eerdere studies hebben aangetoond dat ambulance medewerkers de ernst van het letsel accuraat kunnen voorspellen,[21, 22] zou het nuttig zijn om hun deskundig oordeel op te nemen in de pre-hospitale immobilisatiecriteria. Dit zou een stap voorwaarts kunnen betekenen in het voorkomen van onnodige immobilisatie. **Hoofdstuk 4** richt zich op het potentiële vermogen van ambulance medewerkers om wervelkolomfracturen te voorspellen. Over een periode van 1 jaar werden 139 patiënten opgenomen in een prospectief cohort. Voorafgaand aan de diagnose noteerden ambulance medewerkers de waarschijnlijkheid van een wervelfractuur. Deze voorspellingen werden vergeleken met uitkomst van letsel van de patiënten. Ambulance medewerkers konden de aanwezigheid van een wervelfractuur voorspellen met een nauwkeurigheid van 41%. Deze relatief lage nauwkeurigheid suggereert dat implementatie van een protocol dat alleen gebaseerd is op voorspellingen van de ambulance medewerker het overmatig gebruik van immobilisatie van de wervelkolom niet substantieel zal verminderen.

Hoofdstuk 5 analyseert de pre-hospitale immobilisatie protocollen in een systematic review waarbij er naar het meest betrouwbare en het nauwkeurigste protocol wordt gezocht bij trauma patiënten met een wervelkolomletsel die immobilisatie nodig hebben. Onze uitgebreide literatuurstudie resulteerde in 11 studies die in aanmerking kwamen voor een analyse. Een kritische beoordeling van de geïncludeerde studies toonde aan dat de meeste studies van matige kwaliteit waren. Negen verschillende immobilisatieprotocollen voor de wervelkolom werden geanalyseerd, de meeste met vergelijkbare criteria. Kwaliteitsanalyse op basis van protocol en immobilisatie toonde een hoge sensitiviteit en een lage specificiteit, wat resulteerde in een matige nauwkeurigheid voor de meeste protocollen. Het resultaat was dat geen enkel protocol er bovenuit stak als zijnde beter dan de rest.

De Nederlandse ambulance medewerkers gebruiken een pre-hospitaal immobilisatieprotocol dat in 2010 werd geïntroduceerd en in 2016 werd aangepast.[23, 24] Hoewel dit protocol in overeenstemming is met aanbevelingen uit de wetenschappelijke literatuur, heeft het geleid tot een discrepantie met het protocol dat momenteel in het ziekenhuis wordt gebruikt en dat van het protocol dat pre-hospitaal wordt gebruikt.[15] Dit betekent dat patiënten met een

vermoedelijk wervelkolomletsel mogelijk twee verschillende soorten behandeling krijgen. Het was echter niet bekend hoe vaak dit gebeurt en wat de gevolgen zijn. De retrospectieve cohortstudie in **hoofdstuk 6** beschrijft de aantallen patiënten met verdenking op wervelkolom letsel die secundaire wervelkolom immobilisatie krijgen op de SEH. Van de 563 patiënten die geen pre-hospitale immobilisatie kregen, maar die op de SEH verdacht werden van wervelletsel, onderging 10% vervolgens een secundaire immobilisatie in het ziekenhuis. De incidentie van wervelkolomfracturen in de groep patiënten die secundaire immobilisatie kregen, was in feite lager dan in de groep die dat niet kreeg (7% vs. 12%).

Terwijl de diagnostiek van wervelletsels bij volwassenen meestal volgens de huidige traumarichtlijnen verloopt, ontbreekt het in de literatuur aan bewijs met betrekking tot de toepassing van deze richtlijnen bij kinderen. **Hoofdstuk 7** behandelt de naleving van het protocol en specifiek de timing en het type beeldvorming dat wordt uitgevoerd bij kinderen die verdacht worden van wervelletsel. Wij analyseerden gegevens van alle patiënten jonger dan 16 jaar die verdacht werden van letsel aan de cervicale wervelkolom na een stomp trauma en die zich in twee periodes in ons ziekenhuis hadden gemeld: januari 2010 tot juni 2012, en januari 2017 tot juni 2019. In de tussenliggende periode werd het beeldvormingsprotocol voor diagnostische workup geactualiseerd. We includeerden 170 kinderen in de eerste studieperiode en 83 in de tweede. Eén patiënt in de totale groep werd gediagnosticeerd met cervicaal wervelkolomletsel. De naleving van het protocol met betrekking tot de indicatie voor beeldvorming was > 80% in beide periodes. De naleving met betrekking tot het type beeldvorming nam echter af in de loop van de tijd, waarbij het aandeel patiënten dat een primaire CT-scan kreeg toenam van 2,9% tot 45,8%. Hoewel de richtlijnen voor beeldvorming van de halswervelkolom bij kinderen duidelijk zijn, is het gebruik van CT in het algemeen aanzienlijk toegenomen sinds de invoering ervan voor zowel volwassenen als kinderen, vooral op de SEH.[26, 25] Dit is een reden tot bezorgdheid gezien de mogelijke toename van het levenslange risico op kanker bij kinderen als gevolg van de bij dit type beeldvorming gebruikte straling.

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PHD PORTFOLIO

PhD portfolio

Name PhD student:	J.G. ten Brinke
PhD period:	2012 - 2021
Name PhD supervisor:	Prof. dr. J.C. Goslings

1. PhD training

	Year	Workload (ECTS)
General courses		
Basic course for clinical investigators	2020	1.5
Medical literature: Searching for a Systematic review	2014	0.1
Medical Literature: Endnote	2014	0.1
Good clinical practice	2014	0.4
Evidence-based surgery	2013	0.6

Seminars, workshops and master classes		
Weekly surgical departments seminars	2015-2016	3
Journal club	2015-2016	2
Regionaal refereren regio II	2012-2021	2
Trauma refereren, regio oost	2012-2021	1
Trauma OnderzoeksGroep Apeldoorn (TOGA)	2012-2021	2

Oral presentations		
AO-symposium NVvH chirurgendagen, Veldhoven. • Spinal immobilization	2016	0.5
MMT congres, Zwolle. • Spinal immobilization	2015	0.5
European Congress of Trauma and Emergency Surgery, Amsterdam • Clearing the cervical spine after blunt assault – a pain in the neck? • Incidence of vertebral fractures in the Netherlands, 1997–2012 • Pre-hospital prediction of spine fractures.	2015	1.5

Oral presentations continues on next page

European Congress of Trauma and Emergency Surgery, Frankfurt • The daily practice of immobilizing fractures of the thoracolumbar spine • Pre-hospital immobilization of the cervical spine in the alert patient who were ambulatory on scene after blunt trauma: A retrospective analysis • Clinical clearance of the cervical spine in children with blunt trauma: results in a level-II trauma center. • Prehospital immobilization in suspected cervical spine fractures. • Implementation of the NEXUS criteria in a general hospital in the Netherlands: a retrospective analysis.	2014	2.5
European Congress of Trauma and Emergency Surgery, Lyon • Immobilisation in patients with a C-spine injury: a retrospective cohort study	2013	0.5
NVT traumadagen • The daily practice of immobilizing fractures of the Thoracolumbar Spine	2013	0.5

Poster presentations European Congress of Trauma and Emergency Surgery, Amsterdam • In-hospital immobilization for suspected spinal fracture: is it beneficial?	2015	0.5
NVT traumadagen, Amsterdam • De mishandelde patiënt verdacht voor CWK-letsel: een klinisch obstakel?	2015	0.5
NVT traumadagen, Amsterdam • Pre-hospital immobilisation in suspected cervical spine fractures; a thorn in the flesh of the emergency department. • An overview of pre-hospital immobilisation in patients with a C-spine fracture. • Pre-hospital immobilization of the Cervical Spine in the alert patient who were ambulatory on scene after blunt trauma: a retrospective analysis	2013	1.5

(Inter)national conferences		
Traumadagen	2013-2019	3.0
European Congress of Trauma and Emergency Surgery	2013-2019	2.25
German Congress of Orthopaedics and Traumatology	2014	1.0
Ortopaedic Trauma Association annual meeting	2018	1.0

Other		
President and founder resident association GAAV Gelre Ziekenhuizen, Apeldoorn	2014	2.0
President of the annual sportsevent: chirurgencup	2016	1.0

2. Teaching

	Year	Workload (ECTS)
Tutoring, mentoring, supervising		
Medical student, S. Kovalev	2012	1.0
Medical student, A. Prins	2012	1.0
Medical student, S. Groen	2014	1.0
Medical student, W klein Gebbink	2014	1.0
Physician assistant in training L. Pallada	2015	1.0
Medical student, L. van den Brink	2016	1.0
Medical student, T, Slinger	2020	1.0
Medical student, T Kraai	2021	1.0

LIST OF PUBLICATIONS

List of publications

This PhD thesis

Incidence of spinal fractures in the Netherlands 1997-2012.
Ten Brinke JG, Saltzherr TP, Panneman MJM, Hogervorst M, Goslings JC.
J Clin Orthop Trauma. 2017 Nov;8(Suppl 2):S67-S70.

Prehospital care of spinal injuries: a historical quest for reasoning and evidence.
Ten Brinke JG, Groen SR, Dehnad M, Saltzherr TP, Hogervorst M, Goslings JC.
Eur Spine J. 2018 Dec;27(12):2999-3006.

Value of prehospital assessment of spine fractures by paramedics.
Ten Brinke JG, Gebbink WK, Pallada L, Saltzherr TP, Hogervorst M, Goslings JC.
Eur J Trauma Emerg Surg. 2018 Aug;44(4):551-554.

Accuracy of prehospital spine immobilization protocols following blunt trauma: a systematic review
Ten Brinke JG, van Rein EAJ, Slinger G, Hogervorst M, Goslings JC, Saltzherr TP
Submitted

Secondary In-Hospital Immobilization in Patients with Suspected Spinal Injury: Implications for Treatment and Outcome.
Ten Brinke JG, Groen SR, Detering R, Meijer HAW, Saltzherr TP, Hogervorst M, Goslings JC.
J Orthop Res Ther. 2019 Sep; 4 (7): 1145

Increased and unjustified CT usage in paediatric C-spine clearance in a level 2 trauma centre.
Ten Brinke JG, Slinger G, Slaar A, Saltzherr TP, Hogervorst M, Goslings JC.
Eur J Trauma Emerg Surg. 2021 Jun;47(3):781-789.

Other publications

A Pulsatile Mass in the Right Buttock.
Ten Brinke JG, van Wijk BJ, Groen SR, Slis HW, Klemm PL.
Ann Vasc Surg. 2016 Aug;35:207.e1-3.

The use of mesh in acute hernia: frequency and outcome in 99 cases.
Nieuwenhuizen J, van Ramshorst GH, ten Brinke JG, de Wit T, van der Harst E, Hop WC, Jeekel JJ, Lange JF.
Hernia. 2011 Jun;15(3):297-300.

Small stitches with small suture distances increase laparotomy closure strength.
Harlaar JJ, van Ramshorst GH, Nieuwenhuizen J, Ten Brinke JG, Hop WC, Kleinrensink GJ, Jeekel JJ, Lange JF.
Am J Surg. 2009 Sep;198(3):392-5.

DANKWOORD

DANKWOORD

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CURRICULUM VITAE

Curriculum Vitae

Joost ten Brinke was born on 1 February 1982 in Mariënberg. Together with an older brother and sister he grew up in the beautiful surroundings of 't Salland. After obtaining his VWO diploma, he travelled the world for a year. In 2002 he studied Earth Sciences at Utrecht University, and in 2003 he started his medical studies at Erasmus University Rotterdam. During his studies, he was a junior researcher in the Rotterdam Erasmus Project on Abdominal Innovative Surgical Research (REPAIR) group of professors Jeekel, Kleinrensink and Lange, and was on the first board of the Erasmus Anatomy Research Project (EARP). His internships included a training period at Namanyere Hospital and Haydom Hospital in Tanzania. During his studies he joined the Utrecht student rowing society Triton, and in 2005 he was co-organizer of the 123rd student rowing regatta Varsity. He obtained his medical degree in 2010 and then started as a tropical medicine resident at Gelre Hospitals. In the same year, he also co-founded Outdoor Medicine (outdoormedicine.org), a non-profit organisation that has since developed into an international player in wilderness medicine. Through Outdoor Medicine, Joost has had many wonderful adventures with plenty more planned in the future.

In 2012, he started his training in surgery at Gelre Hospitals (under Dr. Peter van Duijvendijk) and in 2015 he continued this training at Amsterdam UMC (under Prof. Olivier Busch). In 2017, he returned to Gelre Hospitals and spent part of his trauma differentiation at Tygerberg Hospital in Cape Town, South Africa. During his training, he started his PhD in his own time under the supervision of Mike Hogervorst, Teun Peter Saltzherr and Carel Goslings.

In 2018, he started as a fellow in trauma surgery at the Elisabeth-TweeSteden Hospital and in 2019 he completed a combined fellowship at St. Antonius Hospital and UMC Utrecht (under Prof. Loek Leenen). Since 2021, he has been working at the place where he once started, Gelre Hospitals. Joost lives in Utrecht together with his girlfriend Floor van der Hilst and his three children, Hugo, Sofia and Lara.