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Doctoral thesis

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Trondheim, February 2019

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Acknowledgements

I have been told that my first interest in trauma started at the age of three. Playing the character of a lion trying to climb a mountain, this challenging endeavor resulted in a sudden fall down the stairs with high acrobatic value. After discovering the bruise on my knee I allegedly with some surprise concluded: “So this is how I look on the inside!”. As the son of a police officer and a nurse anesthetist and with an elder brother in constant need of a sparring partner for the development of his karate training skills, I was both genetically and environmentally exposed to trauma at an early stage. My path was laid.

As a young resident in anesthesiology at Lillehammer county hospital I was exposed to trauma in a more systematic manner and early started to engage in the establishment of a hospital trauma registry and courses to improve trauma care together with **Ingrid With** and **Johan Storm-Munch**. **Ingrid** and **Johan** introduced me to the importance of administrative duties of trauma care. The head of department, **Dr. Nils H. Hagness,** allowed me to pursue my interest in this field of medicine. In 2003 I started to work at the Department of anesthesia and intensive care at the University Hospital in Trondheim led by **Professor Sven Erik Gisvold.** I am grateful to **Professor Gisvold**, who provided me with the opportunity to continue my professional interest in emergency medicine and trauma. I am also thankful to **Dr. Morten Jensvold** who employed me as flight physician at the Search and rescue helicopter at the Royal Norwegian Air Force 330 squadron at Ørland in 2002 and **Dr. Erik Isern** who after my long and tedious complaining engaged me as a flight physician at the Norwegian Air Ambulance base in Trondheim in 2004.

Professor Eirik Skogvoll and **Professor Petter Aadahl** introduced me to research in 2005 and gave me the inspiration to start summarize findings; write abstracts and even an article. For this I am forever grateful. I thank the trauma coordinators **Ulrika Eriksson** and **Ole-Petter Vinjevoll** for their ongoing commitment to improve trauma care at our hospital and the chance to collaborate with you.

The initiation of my thesis started as a small project following discussions with **Professor Eirik Skogvoll**, **Professor Inggard Lereim** and **Dr. Anna-Catharina Hegstad**. They gave me thoughtful advice and motivated me by their experience and devotion. The project gradually expanded and resulted into a PhD project. **Professor Pål Klepstad** became my main supervisor for which I am deeply grateful. His pragmatic style, his ability to highlight the important things in research, his presence, availability and quick responses are admirable.

Dr. Thomas Kristiansen and **Professor Pål Richard Romundstad** were my co-supervisors. **Thomas** with his relaxed South-Norwegian attitude, his rapid responses and extensive knowledge about trauma was a key factor throughout the entire project. **Professor Romundstad** provided invaluable expertise in epidemiology and methodology which was indispensable throughout the project. **Dr. Kristine Pape** became my co-supervisor following **Professor Romundstad**`s appointment to Dean of Research at NTNU. Her extensive expertise, her analytical skills, support and quick responses was a key factor to complete this project. You all taught me so much and you did it with a smile.

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This work has taught me that research is a long and laboriously process, but that the work with time will mature and improve. It is a team effort, dependent on the persons you choose to have on your team. Luckily I chose wisely.

My mother **Anne-Marie** and my father **Yngvar** died too early to experience this work. I believe they would have been proud of my achievements. They will always be with me.

To my family and friends; thank you for the tolerance, help and patience throughout the years. And more than anything I would like to express my love and admiration for my wife **Jorunn** and our children **Lars, Jens and Mari**. You are the love and joy of my life.

List of papers

Paper I: Uleberg O, Vinjevoll OP, Kristiansen T, Klepstad P. Norwegian trauma care: a national cross-sectional survey of all hospitals involved in the management of major trauma patients. Scand J Trauma Resusc Emerg Med. 2014; 22:64. doi 10.1186/s13049-014-0064-0.

Paper II: Uleberg O, Kristiansen T, Pape K, Romundstad PR, Klepstad P. Trauma care in a combined rural and urban region: an observational study. Acta Anaesthesiol Scand. 2017; 61(3):346-56. doi 10.1111/aas.12856.

Paper III: Uleberg O, Pape K, Kristiansen T, Romundstad PR, Klepstad P. Population-based analysis of the impact of trauma on longer-term functional outcomes. Br J Surg. 2019 Jan; 106 (1): 65-73. doi: 10.1002/bjs.10965.

Acronyms

AAAM	Association for the Advancement of Automotive Medicine
ACH	Acute Care Hospital
ACS-COT	American College of Surgeons - Committee on Trauma
AD	Anno Domini
AIS	Abbreviated Injury Scale
AMK	Akutt Medisinsk Kommunikasjonssentral (equivalent to EMCC)
ARIA+	Accessibility/Remoteness Index of Australia
ASA-PS	American Society of Anesthesiologists Physical Status classification system
BC	Before Christ
BEST	Better and Systematic Trauma care foundation
CI	Confidence Interval
CNS	Central Nervous System
CT	Computer Tomography
DALY	Disability Adjusted Life Years
EMCC	Emergency Medical Coordination Center
EMS	Emergency Medical Services
GBD	Global Burden of Disease
GCS	Glasgow Coma Scale
GOS	Glasgow Outcome Scale
HEMS	Helicopter Emergency Medical Services
HR	Hazard Ratio
ICU	Intensive Care Unit
IQR	Inter Quartile Range
ISS	Injury Severity Score
MTC	Major Trauma Center

NAAS	National Air Ambulance Service
NHS	National Health Services
NISS	New Injury Severity Score
NTNU	Norwegian University of Science and Technology
NUDB	Nasjonal Utdanningsdatabase (National Education Database)
Ps	Probability of survival
REC	Regional Ethics Committee
RCT	Randomized Control Trial
RHA	Regional Health Authority
RTS	Revised Trauma Score
RTW	Return to Work
SAR	Search and Rescue
SPSS	Statistical Package for the Social Sciences
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
TRISS	Trauma and Injury Severity Score
TTA	Trauma Team Activation
UK	United Kingdom
USA	United States of America
WebCRF	Web based Clinical Reporting Form
WHO	World Health Organization
WW	World War
YLD	Years Lost due to Disability
YLL	Years of Life Lost

Sammendrag

Traumesystemet og pasienten – et nasjonalt, regionalt og individuelt perspektiv

Morbiditet og mortalitet som følge av traumatiske skader utgjør på verdensbasis en betydelig helseutfordring både for samfunnet og det enkelte individ. Kunnskap om den historiske utviklingen, epidemiologiske utviklingstrekk og implementering av traumesystemer er et viktig element for å bidra til en kontinuerlig kvalitetsheving av den behandlingen disse pasientene mottar. Selv om skader utgjør en av våre største folkehelseutfordringer har man hatt begrenset kunnskap om epidemiologi og behandling av potensielt alvorlig skadde pasienter, både i Norge og i Midt-Norge.

Delarbeid 1 er en nasjonal tverrsnitts studie som inkluderer alle førti-en norske sykehus som mottok potensielt alvorlig skadde pasienter i 2011. Vi observerte en betydelig reduksjon av antall sykehus over tid og at mange sykehus fremdeles mottok et lite antall pasienter. På et nasjonalt nivå bidro akuttsykehus med traumefunksjon betydelig i den primære vurderingen av traumepasienter. Vi konkluderte med at den fremtidige utviklingen av traumesystemet må ta hensyn til utfordringene med en spredt befolkningsstruktur og geografiske utfordringer veid opp mot behovet for sykehus med tilstrekkelig pasientvolum og behovet for intervensjoner til riktig tid.

Delarbeid 2 er en retrospektiv multisenter observasjons studie som inkluderer 2323 pasienter ved åtte sykehus innenfor et definert geografisk område (Midt-Norge). Vi observerte at kun et lite antall av pasientene ble definert som alvorlige skadde pasienter, og at de fleste av disse pasientene mottok endelig behandling ved det regionale traumesenteret. Akuttsykehus med traumefunksjon bidro i betydelig grad, ettersom mer enn halvparten av alle pasienter initialt ankom disse sykehusene og at majoriteten av disse pasientene mottok sin endelige behandling der. Vi konkluderte med at i en region med et spredt nettverk av sykehus, geografiske utfordringer, lav andel av alvorlige skadde pasienter, er det avgjørende for et bra behandlingsutfall at det foreligger optimal triage, desentralisert kapasitet for tidlig stabilisering og effektiv overføring av pasienter til institusjon med endelig behandlingsmulighet.

Delarbeid 3 er en studie med 1191 potensielt alvorlig skadde pasienter i arbeidsfør alder, hvor man benyttet retrospektive traumeregisterdata fra syv sykehus som ble koblet med nasjonale administrative databaser. Målet var å beskrive sammenhengen mellom hvordan skadealvorlighet på lang sikt påvirker evnen til å komme tilbake i jobb og behovet for

medisinske støtteordninger. Vi observerte at pasienter med mindre og moderate skader hadde to- til tre ganger større risiko for å benytte medisinske støtteordninger i oppfølgings-perioden, sammenlignet med tiden før skaden. Median tid for å komme tilbake i jobb, var henholdsvis 1, 4 og 11 måneder hos pasienter med mindre, moderate og alvorlige skader. Studien bekreftet at alvorlige skader gir betydelige langtidseffekter, men viste også at pasienter med mindre og moderate skader har høyere risiko for negative langsiktige helseeffekter enn tidligere vist.

Samlet bidrar artiklene til økt basiskunnskap om organiseringen, behandlingen og utkomme hos potensielt alvorlig skadde pasienter. Dette er viktig når man skal innføre traumesystemer, foreta analyser av nøkkelindikatorer og evaluere kvalitet innen traumeomsorgen. I tillegg understreker funnene også viktigheten av langtidsoppfølgning hos dem med mindre og moderate skader, som et ledd for å redusere samfunnets totale skadebyrde.

Kandidat: Oddvar Uleberg

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Summary

The trauma system and the patient – a national, regional and individual perspective

Morbidity and mortality following traumatic injuries constitute a substantial global health challenge affecting both the society and the individual. Knowledge of the historical background, epidemiological development trends and implantation of trauma care systems is important to provide a basis for continuous improvement in the quality of care for those affected. Even though the burden of injury constitutes a major public health challenge, there has been insufficient knowledge on the epidemiology and management concerning potentially severely injured patients both in Norway and the region of Central Norway. A trauma system consists of several elements which contribute to a systematic approach and management throughout the chain of care, including injury prevention measures. This thesis consists of three studies relating to key aspects of the health care provided to patients with traumatic injuries; on a national, regional and individual level.

Study 1 was a cross-sectional study including all forty-one Norwegian hospitals receiving potentially severely injured patients in 2011. The aim was to describe the Norwegian trauma system by identifying the number and distribution of hospitals receiving trauma patients, the hospital structure development and the caseload of potentially severely injures trauma patients within these hospitals. We observed that there over time had been a substantial reduction of number of contributing hospitals, and that many hospitals still received a small number of patients. On a national level acute care hospitals contributed substantially in the primary evaluation of trauma patients. We concluded that the future development of the Norwegian trauma system needs to address the balance between a scattered population structure and geographical challenges, and adequate hospital caseloads and need for timely interventions.

Study 2 was a retrospective multicenter observational study including 2323 patients in eight hospitals within a defined geographical region (Central Norway). The aim was to provide a detailed description of epidemiology, resource use, transfers among hospitals and outcomes for potential severely injured patients prior to implementation of a formal trauma system. We observed that only a small number of patients were defined as severe trauma, of which the majority of these received definite care at the regional major trauma center. Acute care hospitals contributed substantially as more than half of all patients initially presented in these hospitals and the majority of them here received their definitive care. We observed a low

mortality of only two per cent among patients included. We concluded that in a region with dispersed network of hospitals, geographical challenges, and low rate of major trauma cases, emphasis on optimal triage, decentralized services` capability of early stabilization, and efficient transfer of patients to definite care is crucial.

Study 3 was a study of 1191 potentially severely injured patients in the working age population, using retrospective trauma register data from seven hospitals linked with Norwegian administrative databases. The aim was to describe the association between injury severity and long term impacts of trauma on return to work and need for medical benefits in these patients. We observed that patients with minor and moderate injuries had a two- to threefold increase in the risk of receiving medical benefits throughout the follow-up period, compared to pre-injury levels. Median times after injury until return to work were 1, 4 and 11 months for patients with minor, moderate and severe trauma, respectively. The study showed that although severe injury is well known to have substantial long term effects, minor and moderate trauma have a higher risk of long term negative health effects than previously shown.

Together, these studies provide increased knowledge regarding organization, treatment and outcome in potentially severely injured patients. This is important when implementing trauma systems, undertaking comparative analysis of key trauma system indicators and evaluating the quality of trauma care. In addition the findings emphasize the importance of longer-term follow up in those patients with minor and moderate injuries in order to reduce the total burden injuries have on the society.

1. Introduction to study

Traumatic injuries as a result of violence and accidents are one of the most profound challenges in most health care systems [1, 2]. In 2013 there were an estimated 4.8 million deaths worldwide caused by injuries and almost 973 million people who sustained injuries which necessitated some need of health care [2]. The age-standardized death rate was 70.0 per 100.000, and injuries were the leading cause of death from 1 to 49 years of age [3, 4]. Even though recent reports have shown a gradual worldwide decline in number of deaths due to trauma, there are considerable regional differences between regions and age-groups [2, 5]. When comparing Norway to international statistics the population-adjusted trauma death rates in Norway are lower; rates from 29 to 77 per 100.000 have been reported, depending on the definitions used [6-9]. Norway has seen a significant reduction of deaths from transport and work-related injuries since the 1970's [10]. However, also in Norway accidents are still one of the most frequent causes of mortality and permanent disability among young adults [10].

In 1976 the American College of Surgeons Committee on Trauma (ACS-COT) published the report "Optimal Hospital Resources for Care of the Seriously Injured" [11]. This was the first major recommendation on how to organize and structure the health care system to provide a continuum of trauma care from the scene of the accident through complete rehabilitation. Since then the development of trauma-systems has evolved throughout the world. Research has extensively documented their beneficial effects with significant reduction in mortality of the severely injured [12-19]. A trauma system advocate both primary preventive measures aimed at reducing the incidence of traumatic injuries, as well as an integrated pre- and in-hospital clinical effort to reduce mortality and morbidity post-injury [20, 21].

In 2007 recommendations for a trauma care system in Norway was published [22]. This report stated that there is a lack of overview of the incidence of potential seriously injured patients [22]. Several reports have also concluded that there is limited national clinical relevant data regarding the total caseload of traumatic injuries [8, 10, 22, 23]. However except for a few hospital-based registries, there were no regional or national trauma registries providing benchmark population-based clinical data in 2014 [24].

An assessment of the quality of care is challenging when there is an incomplete overview of organizational structures, diagnostic and therapeutic interventions and patient follow-up [22, 23]. The outcome measures assessing the quality of trauma care is often restricted to whether a patient survives or not [13, 25] while morbidity or loss of function is usually not reported.

However, over the last decades there has been a shift towards increased focus on defining better outcome measures and several variables have been suggested [25-28].

This thesis focuses on providing new knowledge on epidemiology, management and outcome of potentially severely injured persons in order to provide a better basis for goal oriented quality improvement based on benchmark data. Benchmark data should consist of key system indicators on a national level and detailed information about the epidemiology, injury panorama and practice within a defined geographical and organizational area. Outcome variables assessing and comparing different trauma systems today, mostly define mortality within a system as the main indicator of trauma system quality. In this thesis alternative outcome variables at an individual level are explored, including employment and social-status, thus combining clinical data with national administrative databases.

In this thesis, since the time frame from start of data collection started in 2011 to the end of data collection in 2014, I have chosen to include studies and reports within the section "Review of research" published during this time period and from 2014 to 2017 as several recently published papers provide important background information.

2. Review of research

"If you do not know the past, you cannot understand the present and you cannot shape the future."

German Chancellor Helmut Kohl, German Parliament 1st June 1995

A first step to improve quality of care is to establish an overview of the current situation based on system descriptors, clinical and operational patient data. Data on treatment of potential severely injured patients are today lacking on local, regional and national levels. This type of data should be available when defining future quality improvement strategies in order to avoid implementing standards and quality measures not compatible with or beneficial to the system. Thus, in order to identify and provide a more goal oriented quality improvement, a description of the history, the effects of trauma care systems and consequences after trauma seems warranted.

2.1 Definition of trauma

Injuries, wounds, cuts, bruises, abrasions, contusions, lacerations, avulsions, amputations and many more synonyms, are all forms of describing the unpleasant event of external forces disrupting any normal cellular barrier within our body. These events most often result from sudden exposure to mechanic energy, heat, electricity and ionizing radiation in quantities not tolerable to human individuals [29]. The definition of the word *trauma* can be traced back to ancient Greek and the word *diatitreno* which means "to penetrate", but may also derive from the noun *iatros* which originally meant "extractor of arrows" in ancient Greek and means physician in modern Greek [30, 31]. The earliest recorded classification of the word *trauma* in the Oxford English Dictionary is from a medical dictionary published in 1693, when it was defined as "a wound from an external cause" and is therefore today often referred to as any kind of *wound* [32]. In addition the word *traumatick* was cited in a publication in 1656 referring to "belonging to wounds or to the cure of wounds" [32]. There is no doubt that traumatic events were initially most often treated as physical injuries. Though following the experiences of war in the 19th century the association between physical and psychological aspects became more apparent [32, 33]. Since then, trauma has also been referred to as a "disordered psychic or behavioral state resulting from mental or emotional stress or physical injury" [34]. Reviewing the literature, a PubMed search was performed 12th of April 2018 which found 10.8 million publications related to "trauma". For the purpose of this thesis, traumas relating to psychological references have been left out as it would be beyond the scope of this thesis to encompass all aspects of societal and individual aspects of trauma.

2.2 Historical background

Since man walked the earth for the first time, both lethal and non-lethal traumatic injuries are likely to have been a part of everyday life. Exposed to the harmful consequences of falls, fire, drowning, animals and interpersonal conflicts, the resulting injuries laid the basis for a slow and tedious development of wound and trauma care throughout centuries on which the current modern principles of medicine is based [35, 36]. Reviewing some of the historical milestones made by countless humans throughout time, gives an important context to understand the progress for the care of the wounded.

One of the first accounts of performed trauma care is the trepanation of the skull using stone as tools practiced by the Neolithic man approximately in the year 8000 BC, most likely performed for cranial fractures or epidural hematomas [37, 38]. The earliest form of trauma care were mainly observations and topical applications, though Egyptian surgeons were capable of wound dressing, amputations, fracture splinting and extrication of foreign bodies as early as 6000 BC [35, 39]. Two of the most important medical documents in Egypt, the Edwin Smith (ca 1600 BC) and the Ebers`papyri (ca 1550 BC) describe treatments of wounded patients, of which the former gave a detailed account of 48 cases of trauma [35, 40]. Between 2500 and 1500 BC surgical progress in India was made possible due to procedures such as amputations, cauterization of hemorrhagic wounds, excision of tumors, establishment of dedicated surgical beds and inventions of more than 100 surgical instruments [35, 36]. In more modern times the medical culture of ancient Greek made several improvements for the care of the wounded and laid the foundation of modern medicine [35, 36, 40]. In Homer`s description of the battle of Troy, in which 114 of 147 of individuals died, the injury panorama indicated that war surgery was still mostly successful in treating minor injuries [41]. All thirty-one patients with head injuries died, along with 81 % of those with neck wounds and 85 % of those with wounds to the torso [38, 41]. The Greeks also started to deliver care in special quarters, *klisiai*, or in ships [38]. The transition from performing medical care based on empirical medical science and without magic rites or conjurations was a key turning point [41]. Further developments were accelerated by the Romans who based on Greek medicine improved several surgical techniques which are described in some of the 400 authored works by Galen (AD 130-200) [40]. The first establishments of centralized trauma care are difficult to locate, but these were most likely linked to war and conflicts. Initially wounded roman soldiers were cared for in the homes of the rich, later tents were established separated from normal barracks, before army hospitals named *valetudinarian* were established close to the battlefield containing supplies and medications [35, 42]. The remains of 25 such centers have been found [38].

Following the fall of the Roman Empire in 476 AD, medical knowledge was further developed by the Greeks and partially preserved and transmitted to the Arabs, but failed to improve significantly after both Christian and Islamic edicts were issued against surgery [35, 40]. Though the renowned Arab surgeon, Rhazes (AD 865 – 925), was the first to use animal gut for ligatures and use of warm moist compresses for bowel preservation during surgery [43]. Following several edicts in the years 1130, 1163 and by the Pope Innocent III in 1215, surgical practice was removed from the practice of physicians and needed operations were then mainly performed by barbers and hangmen [40, 44]. Fortunately medical progress continued as Italian universities (900-12500 AD) in Salerno and Bologna continued to educate physicians and the first text books of accumulated surgical knowledge were published [44, 45]. During the Renaissance (1400 – 1600) ancient skills were refined, at the same time when wounds due to gunshots became more common [46].

During the 16^{th} and 18^{th} centuries medicine became consolidated as a science. The American Revolution conveyed a hierarchical military hospital structure, though effective measures to establish a centralization of the care of injured, stranded due to personal disagreements, poor education of physicians and limited resources [40, 47]. Baron Dominique Jean Larrey, the personal physician of Napoleon, accompanied Napoleon during 18 years, 25 campaigns, 60 battles and 400 skirmishes [48]. During that time he, together with Pierre Francois Baron de Percy, developed the rapid battle field evacuation service known as *ambulances volantes* “flying ambulances” (Battle of Metz in 1793), a three scale severity triage categorization (Battle of Jena 1806) and establishment of battlefield hospitals (1807) [48, 49]. Successive developments such as introduction of general anesthesia in 1846 [50], antiseptic surgery in 1867 [51] and x-ray as an imaging modality in 1895 [52], caused major breakthroughs with pain free surgery, reduced mortality and improved diagnostics. During the American Civil war (1861-1865) increased focus on the knowledge and capabilities of the operating surgeon has been described as “one of the most momentous medical reforms to come out of the Civil war” [40, 46].

During the First World War (WW I) increased use of surgical specialists at evacuation hospitals and mobile units, the first attempts of blood transfusion, implementation of anti-tetanus serum and use of motorized vehicles, revealed the need for close cooperation between civilian inventions and military systems [53]. Establishment of a neurosurgical trauma registry by Dr. Harvey Cushing during WW I led the path to evaluate outcome and to improve treatments modalities which allowed for integrated and planned research in the field of trauma [53]. The use of motorized evacuation reduced the time from injury to definitive treatment from 3 days to 12-18 hours, a strategy that was enhanced during the conflicts to come [54]. In World War II (WW II) aeromedical evacuation became an integral part of the casualty care system, which further improved in the Korean and Vietnam conflict after the introduction of helicopters reducing time from injury to a definitive treatment facility at 4-6 hours in Korea and to 1-5 hours in Vietnam [54]. Additional important improvements were use of antibiotics and transfusion of blood products and availability of trained surgeons during WW II. All these and more achievements led to a hospital mortality reduction among admitted wounded troops in the US Army from 8.5 per cent during WW I to 2.3 per cent during the Vietnam conflict [40].

As advancements in trauma care through centuries had been unavoidably linked to armored conflicts, the wars of the 20th century sparked new discoveries and the start of the modern symbiosis between military and formalized civilian trauma systems [53]. In 1925 the first civilian trauma system was established by Lorenz Böhler in Vienna (Austria) to care for those injured in industrial accidents, but by WW II also included those injured in motor related accidents [55, 56]. The Birmingham Accident hospital (United Kingdom [UK]) including a rehabilitation unit was the first trauma center established in 1941 [56, 57]. This happened as, in addition to continuous air raids, the influx of unskilled labour to Birmingham`s factories led to a 40 % increase of industrial injuries [57]. This hospital remained the only UK trauma center until 1988 when a report on preventable trauma deaths led to further initiatives towards establishing a UK trauma system [58]. Despite the formidable knowledge of trauma care from armed conflicts, the general implementation into civilian systems was slow, and treatment remained better for the injured soldier than for the injured civilian [39].

In addition to the casualties of war, the industrialized revolution increased the magnitude of injuries and injury was considered a price of economic development and not regarded as a preventable event [59]. After miraculously surviving a plane crash by a seatbelt during WW II, Hugh de Haven, began to study the mechanism of injury. Along with the work of John

Gordon and by using the epidemiologic approach of host, agent and environment, this increased the understanding of biomechanics in injuries [60, 61]. Gordon suggested that injuries, could be characterized like classic infectious diseases by factors such as seasonal variation, long-term trends, and geographic, socioeconomic, and rural-urban distributions [62].The further work by William Haddon Jr., published in 1968, was the first paper describing the underlying causes and opportunities for prevention of traumatic injuries by using several explanatory variables, named the “Haddon matrix” [29] [62]. The matrix provided a framework for developing interventions in the pre event phase, when preventive measures are most cost effective [39].

In the USA in 1965, accidents had become one of the leading causes of death among persons between the age of 1and 37, with a total number 52 million accidental injuries, 107.000 deaths, 10.5 million disabled and at a cost of approximately $ 18 billion. This resulted in the seminal paper “Accidental Death and Disability, the Neglected Disease of Modern Society” which provided specific recommendations on key aspects of systematic trauma care [63]. The report also strongly recommended cooperation among medical professionals and the public, including the importance of the authorities providing guidance and funding. In 1966, trauma centers were established in Chicago and San Francisco, and the first statewide trauma system was established in Maryland (USA) in 1969 [38] and in Illinois in 1971 [64] . In 1976, the ACS-COT published the “Optimal Hospital Resources for care of the seriously injured”, which provided detailed requirements for the specialized trauma hospital and laid the basis for the *exclusive* trauma system, providing detailed descriptions on organization, characteristics and components of the three tiers of trauma center commitment [11]. As subsequent revisions were published in 1990 and 1993 the importance of all components caring for the trauma patients were encompassed [21]. The term *inclusive* trauma system was first used in 1991, including all facilities caring for the injured [65] [66].

Outside the USA, trauma system development was slow, except the German system which after establishment of a trauma system in the 1970s observed a mortality reduction of major trauma patients from 40 % in 1972 to 18% in 1991 [67]. Several regions worldwide have adopted the principles of systematic trauma care proposed by ACS-COT, still, by 2014 there were only a few *nationwide* trauma systems despite several reports describing the need for more adequate care [56, 68-70].

2.3 Epidemiology of trauma

2.3.1 The global perspective

Traumatic injuries as a result of violence and accidents are globally recognized as a leading cause of death and disability and pose a great challenge on existing health care systems nationally, regionally and on the individual level [1, 2]. Early ethnographic and archeological evidence described that "*the levels of violence was much higher than in modern state societies and in the world today*" [71]. Violent deaths were then anticipated mainly to be caused by homicide, wars and battles and showed considerable higher rates in non-state societies compared to state societies. In non-state societies incidence rates were ranging from 20 to 1450 violent deaths per 100.000 persons per year and from 0.33 to 250 per 100.000 persons per year in state societies [71].

In 1990, the first of several Global Burden of Disease (GBD) reports was published in order to provide a global oversight of the burden of disease and associated risks [72]. Approximately 5 million people died annually (10 % of total deaths) due to injuries of all categories, representing the most common cause of death among men aged 15 - 44 years and fifth most common cause among women [72]. A World Health Organization (WHO) update based on figures from 2002, reported the same annual mortality, equaling a mortality rate of 87.3 per 100.000 persons [73]. A systematic analysis of the development from 2006 to 2016, found a 14.4% decrease to 4.6 million deaths in 2016, representing rates from 75.3 deaths per 100.000 persons in (2006) to 64.4 deaths per 100.000 persons (2016) [74]. The 2013 GBD report also described that in addition to the 4.8 million persons who died of injuries, approximately 973 million people sustained injuries requiring some type of healthcare [2].

Substantial geographical differences are observed in the distribution of trauma. Comparing low- and high income countries, 80 % of the world`s total global injuries are associated with low-income regions [75]. Region specific trends have also been described with a significant decline in burden of injury in 17 of the 21 GBD regions, with the exception being Oceania and three of four African regions [2]. Unintentional injuries (falls, drowning and exposure to mechanical forces) are responsible for most deaths due to trauma (1. 8 million deaths in 2016) followed by transport injuries (1.4 million deaths) and self-harm and violence (1.2 million deaths) [74]. Penetrating trauma show a wide variation with high rates described in USA (20-45 %) and South Africa (60 %) [75]. The anatomical causes of death vary, though injuries to the central nervous system (CNS) and trauma causing uncontrollable hemorrhages (e.g. aortic, chest and pelvic) are the most dominant causes [75-77]. Several publications also describe a high rate of prehospital deaths ranging from 51 to 78%, which may represent system dependent factors and should be taken into account when comparing systems [9, 76, 78]. Caution when interpreting differences between studies should also be advised as inclusion and exclusion criteria tend to vary. Prehospital deaths and different mechanism of injury (hanging, drowning, electrocution, drowning, poisoning and asphyxiation) are not always included [76, 79].

Although mortality is an easily definable outcome measure, other measures to address the burden of disability have been recommended as more people survive their injuries. Disability-adjusted life years (DALYs) describe the burden of disability and are a summation of "Years of Life lost" (YLL) and "Years Lost due to Disability" (YLD) and can be considered as "*one lost year of healthy life*" [80]. From 1990 to 2013 the injury DALY rates decreased by 31 % [2]. Seen in conjunction with reduced mortality rates, this indicates an improvement of all aspects of trauma care, though with considerable variations among sex, age and geographical regions. The male population is most prevalent in all age groups, except when aged 80 years and above where the sex differences disappears [2]. A study by Kehoe et al. described a significant increased mean age (from 36 years in 1990 to 54 years in 2013) indicating a change in the epidemiology of the trauma population, combined with change of injury mechanisms towards low-energy injuries [81]. This is especially seen in mature health care systems [76, 77, 81].

2.3.2 The Norwegian perspective

As in many other countries around the world, mortality and morbidity as result of traumatic injuries has been recognized as a public health challenge in Norway. In 2014 a report from the Norwegian Institute of Health also acknowledged the lack of current knowledge to provide a full overview of the impact of injuries in Norway [8]. There is no national injury registry capturing all injuries independent of injury severity, and existing registries are mostly non-overlapping, sector specific and lacking in quality and coverage [8]. Therefore complete national population-based incidence rates cannot be calculated, and are merely estimations. An exception is the Norwegian Cause of Death Registry which provides mortality data and cause of death for Norwegian citizens.

Since 1951 there has been a continuous reduction in the number of deaths caused by traumatic injuries [8]. These injuries include unintentional injuries, homicide and suicide. Among men these rates declined from 94 to 67 per 100.000 person years and from 49 to 35 per 100.000

person years in women between the years 1951 to 2012 [8]. In 2011 a total of six percent of all Norwegian deaths were trauma related with an overall estimated 52 deaths per 100.000 person years. The majority of these were unintentional injuries with 39 deaths per 100.000 person years [8]. A study by Hansen et al. from 2000 to 2002 from the western part of Norway observed an incidence rate of severely injured patients of 30 per 100.000 persons. These figures are substantially lower than national figures and might rely on inclusion procedures [6]. Severely injured patients were defined as an injury severity score (ISS) > 15 or prehospital death. In addition those patients with drowning, asphyxia and poisoning were not included, which might explain the lower incidence rates [6]. Performing an autopsy study, Soreide et al. (1996-2004) observed an annual mortality rate of 10 per 100.000 persons [82], whereas registry studies performed by Wisborg et al. (1991-1995) described a mortality rate of 77 per 100.000 persons [83] and Bakke et al. (1995-2004) with a mortality rate of 61 per 100.000 [84]. In a population-based study Kristiansen et al. investigated persons between 16 and 66 years of age and found a national trauma mortality rate of 29 per 100.00, with higher risk in rural areas and with a proportion of 78 % of deaths occurring outside hospitals. When comparing with other countries, Norway has a high rate of accidental poisoning and fire, but lower transport,- fall and drowning related mortality [8].

When estimating the impact of burden of injury it seems reasonable to also account for those with non-fatal injuries. In a national health survey performed by Statistics Norway in 1985 an estimated 650.000 (~15.7 % of a population of 4.145 million) persons attended any kind of healthcare following injury [85]. In 2014 these numbers were reduced to approximately 540.000 persons (10 % of the population), of which 2577 deaths were reported [8].

2.4 Trauma systems – the elements

The purpose of a trauma system is to provide an organized and systematic approach which reduces the incidence of traumatic events, reduce the morbidity and mortality of injury for all those injured, and optimize rehabilitation and the return of the injured patient to society [20, 86]. Getting "*the right patient to the right place at the right time*" has been one of the doctrines of modern trauma care, in the North-American trauma literature often equivalent with bringing the patient to a high level trauma center (exclusive system) [87]. Historically, the trauma systems were considered *exclusive*, meaning that only the most severely injured patients were included, and the system was centered around high-volume urban trauma centers. As the ACS-COT in 1976 developed criteria for designation of trauma centers, these centers also became the hubs of the regional trauma systems [11, 88]. Recognizing the need for improved trauma care also within rural areas, and for those less severely injured led to the development of the more *inclusive* systems [65]. The inclusive system utilizes an "*all-encompassing*" pre-planned approach including all phases of the injury cascade including injury prevention, pre-hospital care, hospital care and rehabilitation and is preferred as the mode of system approach in most recent guidelines [21, 86]. Regionalization of trauma care adapts the principles of the inclusive model within a defined geographic region to ensure timely and appropriate access to health care of all patients [21]. In the 2014 publication by ACS-COT the principle aim of the trauma system was described as "*The needs of all injured patients are addressed whenever they are injured and wherever they receive care*" [21]. Importantly though it is a key distinction that even if trauma systems were described as establishing norms of care for all persons injured regardless of injury severity, they tended and still tend to focus mainly on those with potential severe trauma and/or those with life threatening injuries [21, 86].

In addition to medical reasons, equally important parts of the trauma system from a systems perspective are economic, legislative, administrative, public health factors and research, which comprise vital elements to ensure implementation of a complex system, facilitate cooperation among several services involved and provide continuous quality improvement strategies [86]. Historical slow and limited development of trauma systems can partly be attributed to the lack of adequate funding [88].

Based on experiences, publications and systematic reports from North-American trauma systems, many regions and countries globally have adapted many of the same trauma care principles [56]. But although the aim of a trauma system is similar in each country, there are regional differences. Geographical challenges, trauma epidemiology, trauma patient volumes and available resources, are likely to cause country-by-country variations in system configuration, needs and outcomes [89, 90]. In addition, the integration of specific cultural, social and historical background is a key component to achieve a well-functioning implementation of systems developed in a different system context [91]. The most optimal system for management of trauma remains controversial, but should contain the elements of: injury prevention, trauma service access, pre-hospital care and transportation, in-hospital care, rehabilitation and quality care [21, 86, 88]. A continuous effort to evaluate process and structure variables and clinical outcomes with the use of integrated trauma registries is essential to improve the quality of care within the trauma system [86].

2.4.1 Injury prevention

The principle aim of injury prevention is to avoid the traumatic event before it happens, but if it happens (primary prevention) reduce the severity at the time of occurrence and diminish the impact post-injury (secondary prevention) [86]. In 1949 Dr. John E. Gordon described an approach to deal with accidents like programs for the prevention of mass disease: «*This includes first an epidemiologic analyses of the particular situation, an establishment of causes, the development of specific preventive measures directed toward those causes, and finally a periodic evaluation of accomplishment from the program instituted*" [61]. Still for a long time, injuries as a result of accidents were seen as randomly occurring, unpredictable events. The expansion of Gordon`s work by William Haddon led to the understanding of the interaction of factors such as host, agent and environment, known as the Haddon matrix [29, 62]. Since the 1980`s and 1990`s these initiatives have gradually been incorporated in public health systems [86], though implementation rates have been considered slow [92]. Despite considerable evidence to support injury prevention initiatives, their implementations have often been troubled by low political attention, few dedicated resources and lack of visibility of the problem [93, 94]. Major advances have been made in some countries (e.g. Germany and Sweden) and where the lower injury rates is associated with investments that have been "*in safety as a societal responsibility, rather than delegating this to individuals*" [91] [94]. Several publications have observed that effective injury and violence prevention strategies are cost-effective [95, 96]. Reduced injury incidence rates is therefore seen as an important contributor in improving outcomes for injured patients, and have been incorporated as an integral part of modern trauma systems [21, 86].

2.4.2 Pre-hospital trauma care

The principle aim of pre-hospital trauma care is to achieve effective identification of the patient, prevent further injury, initiate prompt resuscitation and provide a safe and timely transport to the most appropriate facility [21]. Resuscitation includes the evaluation and immediate therapeutic measures of the severely injured to secure airway, providing adequate breathing, hemorrhage control, fracture stabilization and immobilization of the spine to prevent further neurological damage [21]. It is recommended that time-consuming field interventions should be avoided to reduce pre-hospital time intervals in order to rapidly transport the patient to a definite care facility [21]. Pre-defined criteria should assist prehospital personnel in the triage of injured patients, safely identifying those who require trauma center admission and/or reception by a multidisciplinary trauma team. Measures of physiologic derangement, anatomical injuries and mechanism of injury likely to cause severe injury in addition to history of comorbidity, pregnancy and age are included in these criteria [97].

Some system-specific pre-hospital controversies exist, which differs between trauma systems and regions. The use of specially trained physicians (most often anesthesiologists or emergency physicians) is most prevalent in Europe and Australia, compared to the North-American paramedic-staffed systems. This permits more advanced point-of-care diagnostics, complex decision making and more advanced interventions [98]. Though the balance between the need for an immediate intervention (e.g. advanced airway intervention) with prolonged scene times [99] versus injuries with immediate need for surgical hemorrhage control [100] must be found. Recommendations support the use of helicopter for rapid transport, but their cost-effectiveness is often debated due to conflicting literature on safety and the effect of outcome [101]. Both these factors might affect the use of other trauma care resources, the flow of patients within a defined geographical region and eventually outcomes. As the majority of trauma deaths happen in the pre-hospital phase [6, 9, 82], a well-functioning pre-hospital trauma system with a balanced and integrated use of available resources is crucial to reduce patient mortality and disability.

2.4.3 In-hospital trauma care

The key concept of hospitals within a trauma system is to provide definite care, dependent on the different clinical needs of the patient and the capacity and dedicated resources of the hospitals. Following recommendations from the ACS-COT, hospitals should be differentiated into Level I (highest level) to V (lowest level) [21] following an accreditation process. A

Level I hospital is characterized by a high trauma volume, availability of all relevant clinical specialties, in-house staff, advanced intensive care unit, interventional radiology, rehabilitation and compulsory educational and research activities [21]. Whereas the lower level hospitals should provide definite care for those with minor and moderate injury, and provide resuscitation and/or stabilization prior to transfer to higher level hospitals for the severely injured. In UK and European terms, a Level I hospital would often be equivalent of the major trauma center (MTC) [102], regularly the largest regional hospital. Additional function of the MTC is the coordinated management of severely injured patients within a health region [102].

The benefit of major trauma center care is limited to those patients with the most severe injuries [14, 15]. Transporting all injured patients to trauma centers, would potentially both overwhelm these centers, affect emergency medical systems (EMS) negatively (e.g. increased travel distances) and increase costs [103]. Therefore pre-hospital triage and destination protocols are essential when deciding where to transport the patient [21, 97]. Availability of pre-defined inter-hospital transfer agreements is also seen as a key component of the trauma system with the aim of ensuring rapid transfer of patients in need of higher level of care [104, 105].

Availability and use of dedicated multidisciplinary trauma teams are an important initial phase of the in-hospital management. These teams are independently associated with improved survival in patients with severe injury [106]. Trauma center admission in minor injuries (*overtriage*) and failure to transport to or use trauma center capacity in those with severe injury (*undertriage*) is a well-recognized challenge within several trauma systems [103, 107-109].

2.4.4 Rehabilitation

The principle aim of trauma care and implicit rehabilitation services, is to restore the patient to preinjury status and promote societal re-integration [20, 21]. Any non-fatal injury may inherit a complex range of impairments containing a mixture of physical, emotional, cognitive, social and behavioral complications [110]. Their therapeutic needs span from frequent ambulatory assessments including health care counselling regarding strategies in patients with minor and moderate injuries to complex rehabilitative pathways seen in severely injured patients [110] [111]. As rehabilitation services previously have not been adapted as an integral part of the trauma system, good scientific evidence on the effects of rehabilitation in major trauma has been lacking [112]. In patients with specific injuries (e.g. traumatic brain injury) evidence supports rehabilitation both with improved outcomes and as a cost-effective measure [113, 114]. Rehabilitation services is therefore recommended as an integral part of the trauma system [21] [115].

2.5 Trauma systems – general aspects

2.5.1 The effects of a trauma system

From 1960 to 1982 eleven studies showed a rate of preventable deaths *or* inappropriate care rate ranging from 18 to 73 % [116]. Among these studies was a publication by West et al. which compared two different systems (Orange County and San Francisco). This study indicated that patients who were admitted to the closest hospital (Orange County), compared to those admitted to a single urban hospital (San Francisco) received suboptimal care [117]. A follow-up study published in Orange County in 1983 following implementation of five designated trauma centers, resulted in the reduction of preventable deaths from 73 % to 9 % when patients were treated at one of these centers. If a patient was wrongly triaged to a non-trauma center, the mortality remained at 67 % [118]. This study is regarded as one of the first pre and post studies evaluating the effect of trauma system implementation [116]. Similar studies were performed in San Diego, USA in [119, 120] and Portland, USA [121, 122] with comparable observed reduction in preventable deaths. During the 1970s West-Germany established the first known national trauma system by implementing the experiences made by USA troops in Vietnam [116]. This resulted in a 25 % mortality reduction (from 16.000 to 12.000 annual deaths) following implementation of injury prevention initiatives, rehabilitation programs, trauma centers along the autobahn and a national air rescue service [91, 116].

A systematic review by Mann et al. investigated trauma systems in the USA and Canada from 1962 to 1998 [123]. Reviewed panel studies suggested a 50 % mortality reduction of preventable deaths with implementation of trauma centers, trauma registry studies from trauma centers reported a 15 % mortality reduction and population-based studies observed a 15 to 20 % mortality reduction following trauma center/system implementation [123]. Though the authors underlined that the scientific evidence only fulfilled Class III [124] and that failure to include pre-hospital deaths, survival status beyond in-hospital mortality, functional outcome and appropriate use of comparison groups reduced the reliability and validity of the results [123]. Chiara et al. also underlined that panel studies had limitations due to their subjectivity in their methodology, but that they could be regarded as structured case series [125].

A further systematic review and meta-analysis of population-based studies by Celso et al. in 2006 reported a 15 % reduction in mortality in the presence of a trauma system [19]. Improved odds of survival were observed in eight out of fourteen included studies, whereas three showed worse and three showed non-significant difference [19]. A literature review by Lansink et al. on trauma systems in the USA described beneficial effect of trauma systems, and *inclusive* systems were found more favorable than *exclusive* systems [126]. In a study by Utter et al. the trend towards more inclusive trauma systems improved the odds of survival significantly [66]. Additional publications documented that regionalized trauma systems improved outcome and were cost-effective [14, 127, 128]. Demetriades et al. also showed an increased effect in patients with the most severe injuries [129].

With the exception of the German national trauma system [91], the effects of trauma system implementation in Europe did initially not prove as beneficial as in the USA. In a Swiss prospective observational study, authors could not demonstrate any significant mortality reduction [130]. In 1992 a pilot trauma system implemented in Stoke-on-Trent, UK, only reported modest improvements [131]. A more recent longitudinal analysis over a longer period of time within the same region, documented reduced mortality of the severely injured [132]. These latter findings support other studies suggesting that implementation of trauma systems have a delayed effect on outcomes as these systems need time to embed and that this may take up to ten years to stabilize [133, 134]. Recent studies in UK [135], France [136], Italy [137], Germany [17, 138], The Netherlands [16], Canada [139] and Australia [140] have reported reduced mortality following implementation of trauma systems. Other than most studies, the Australian study also included functional outcome. Similar beneficial effects of single trauma centers with reduced mortality rates were also observed in Denmark [141] and Norway [142]

Reported limitations of the majority of studies evaluating trauma systems are that they primarily focus on patients with severe injury (defined as an ISS > 15) and use only short term mortality (e.g. in-hospital mortality) as the outcome [102, 140]. Despite recommendations of the need for a higher prioritizing of functional and quality-of-life outcomes in trauma research [140] few studies have evaluated long-term effects on quality of life both in the severely injured and in the broader spectrum of population-based non-fatal injuries. In that sense it seems natural that "*evaluation methods of trauma system performance are needed to evolve along with trauma system maturation*" [19].

2.5.2 Patient volume and outcome

One of the fundamental principles within trauma system recommendations is to provide a rapid identification of those potentially most severely injured and transport to a health facility capable of providing definite care [21]. In most cases a definitive care facility means a trauma center, based on the assumption of an inverse relationship between patient volume and mortality [143]. This has been the basis for establishment of trauma centers, though the relationship between patient volume and outcome is still debated [144, 145]. Several publications have shown that increased patient volume is associated with better outcomes in severely injured (ISS > 15) patients [143] [144] [129, 146]. In a study by Zacher et al. there were no clear cut-off values on volume, but at least 40 severely injured patients per year per hospital appeared beneficial for survival [144]. Similar observations have been found within other surgical specialties [147-149]. A systematic review by Caputo et al. investigating studies describing the relationship between patient volume and survival in American trauma hospitals from 1976 to 2013, found inconclusive results [150]. In ten out of sixteen studies, high institutional volume was associated with increased survival, of which half of these studies only found some benefits in subpopulations. No beneficial effect was observed in six studies [150]. In addition the debate of volume per hospital or volume per surgeon as most indicative of a beneficial outcome has been raised [143]. A study by Zafar et al. investigating outcomes after general emergency surgery comparing teaching versus non-teaching hospitals demonstrated comparable results between the two types of hospitals [151]. Reasons for inconclusive results are described to be due to methodological limitations [145, 152].

According to the trauma recommendations by ACS-COT a Level I trauma center should admit at least 1200 trauma patients annually, whereas 240 should have an ISS > 15 [21]. A volume of more than 35 major trauma patients per year per trauma surgeon was also suggested by Konvolinka et al. [153]. In the UK guidelines from 2009, it is suggested that MTCs should admit at least 400 major trauma patients per year, though the exact definition of major trauma is not included. Each MTC should therefore provide service for a population size of approximately 2-3 million people [154]. These suggestions would be in accordance with a regionalization process, as suggested in previous trauma recommendations [11, 20, 21]. In a Norwegian context this would suggest the establishment of one to two MTCs serving the entire nation an organization not feasible due to geographical distances. For that reason a carefully balanced adaption of acknowledged trauma recommendations weighted against national, regional and local needs as well as political, economic and medical aspects is needed [155].

2.5.3 Rurality

«It is surprising that a disease that kills rural citizens at nearly twice the rate of urban citizens has not received more attention"

Rogers et al, Journal of Trauma, 1999 [156]

The challenge of rurality has been described by several authors, observing increased mortality among patients injured in rural areas compared to more urban settlements in the USA [156], Finland [157], Australia [158] and Norway [9, 84, 159]. Rural settings are characterized by lower population density, in addition to longer time frames both in discovery of incidents, recovery of the injured, response times and times to patients arriving definite care [88]. All these factors result in both a higher rate of deaths before and after arrival in hospital. The development of inclusive trauma systems were intended to address these issues by including all components of the health care system involved in trauma care (e.g. EMS and helicopter emergency medical systems [HEMS], local hospitals and trauma centers) to ensure direct transportation to definite care of those severely injured or in need of immediate lifesaving interventions [21]. Despite improved survival in some rural areas for those most severely injured [66] [160], the need for better coordination, training, education and establishment of transfer protocols is warranted [88].

Several definitions are used to describe rurality. According to the American College of Surgeons (ACS), rural trauma is defined as *"trauma in which there is delayed or limited optimal care of the injured patient due to geography, weather, distance, or resources"* [21]. This is however a very non-operational definition for research purposes. The US Bureau of Census define urban areas as regions with 50.000 or more inhabitants, urban clusters with a population from 2500 to 50.000 and rural areas as all population, housing, and territory not included within an urban area or clusters [161]. In Australia the so-called Accessibility/Remoteness Index of Australia (ARIA+) score has been developed to describe the ease or difficulty to access services in a rural area with values ranging from 0 (high accessibility) to 15 (high remoteness) [162]. Using the above mentioned definitions, large parts of Norway, would be referred to as a rural area, or more correctly mixed urban-rural.

2.5.4 Injury severity

Defining severity of injury serves purposes such as triage, prediction of prognosis (e.g. mortality), evaluation of system performance and the ability to quantify levels of injury burden across populations [163, 164]. Several scoring systems have been developed since the 1970s and are primarily divided into 1) anatomic scorings systems 2) physiologic scoring systems 3) comorbidity scoring systems and 4) a combination of the first three [163]. Their ability to predict survival status immediately or as a short-term survival after injury has been the most common usage and their values have further been translated into categories of severity. Physiologic scores (e.g. Revised Trauma Score [RTS]) include clinical factors such as respiratory rate, systolic blood pressure and level of consciousness, variables which are readily available and appropriate for use in triage. As these variables are constantly changing and dependent on host factors (e.g. comorbidity, medications etc.), these injury scores have proven less usable for comparison across different populations and trauma systems [163]. Anatomic and comorbidity scores are seldom available in the field and less suited for prehospital triage [163].

Anatomic scores such as the Abbreviated Injury Scale (AIS) was developed in the 1960s and introduced in1971 and was the first broadly implemented injury score primarily designed as a tool "to describe the severity of injuries throughout the body" following automobile accidents [165, 166]. The AIS is a consensus-based severity score and assigns each anatomical injury within nine body regions using a 6-digit unique numerical identifier and a severity code (ordinal scale from 1-minor to 6-maximal). In 1974 the ISS was introduced in order to include multiple injuries [167]. The ISS is based on the AIS methodology, where each injury is assigned a severity code and a body region. The ISS score is the sum of the square of the AIS score of the three most severe injuries in the six ISS body regions and ranges from 0 (minor) to 75 (worst outcome). An AIS score of 6 automatically assigns an ISS 75, reflecting a non-survivable injury.

$ISS = AIS^2 + AIS^2 + AIS^2$; only the three most injured body regions

The first description by Boyd et al describing the ISS > 15 as being predictive of 10 % mortality, has been a major contributor to define severe injury [168]. Early publications also described that ISS also correlated well with length of stay, need for major surgery and extent of permanent disability [169, 170]. As trauma care systems, trauma epidemiology and the AIS methodology has been revised, the continuous ability of the ISS to describe severe injury and predict mortality have been debated [164]. The inability to assign several severe injuries within one body region with ISS, led to the implementation of the New Injury Severity Score (NISS) [171]. This score uses the same methodology as the ISS score, ranges from 0 to 75, but incorporates the three most severe injuries regardless of body region.

$NISS = AIS^2 + AIS^2 + AIS^2$; the three most severe injuries regardless of body region

With this modification, the predictive ability in penetrating trauma and isolated head injury is improved [171-173]. The Trauma and Injury Severity Score (TRISS) model which incorporates RTS values (Glasgow Coma Scale, systolic blood pressure and respiratory rate), age, penetrating/blunt mechanism and ISS, is one of the most widely used prediction models, but is still not implemented in many systems due to its complexity. In addition TRISS coefficients developed from a North-American trauma cohort to calculate probability of survival (Ps), are invalid for direct comparison within a European trauma population [75].

Although there is still an ongoing debate on which injury severity score which is more precise, the use of ISS is despite its inherent limitations used as a “gold standard” throughout international trauma literature providing a common benchmark variable [164]. The ISS is also commonly divided into three groups of severity; ISS 0-8 (minor injury), ISS 9 – 15 (moderate injury) and ISS > 15 (severe injury/major trauma) [174].

In this present study we defined severe injury / major trauma as an ISS > 15, moderate injury as an ISS 9 – 15 and minor injury as an ISS 0 – 8. We also used the term “potentially severely injured” describing those warranting trauma team reception based on hospital specific activation criteria.

2.6 Trauma care in Norway

Norway has a scattered and low population density of ~ 16 inhabitants / km^2, with a population of 5.109.000 inhabitants (in 2014) distributed over 323.779 km^2 [175, 176] and with considerable differences in population density among counties ranging from 1.5 to 1129 inhabitants/km^2 [9] . Population settlement is mixed urban-rural with 80% of the population living within 976 settlements (in 2014) (a settlement is defined as: more than 200 inhabitants per defined area) [177]. Norway has a well-developed health care system providing equal access to publicly funded health care, long life expectancy after birth, low rate of violence and among the lowest mortality rates following cancer and cardiovascular diseases [178].

In 1998, a Norwegian national white paper report estimated that an improvement and optimization of trauma of care could give a 20-25 % mortality reduction, saving an additional 5000 – 6000 life years lost to traumatic injuries [179]. In 2007, a national working group appointed by the regional health trusts published new recommendations on a formalized trauma care system in Norway [22]. This report described the lack of formal trauma services and recommended the implementation of a trauma system following the principles described by ACS-COT [20, 22]. By 2012 all regional health authorities had ratified the 2007 trauma system recommendations and implementation was initiated. However, in 2014 several components of the proposed trauma system were not yet implemented.

Injury prevention has been an important part of Norwegian healthcare since the first epidemiological description of population mortality by Dr. Eilert Sundt in 1855 [85, 180]. A report by the WHO in 2008 documented that based on 99 recommendations on injury prevention by the WHO and the European Council Recommendation; Norway had implemented 84 % of effective interventions, versus a median European score of 73 % [181]. In 2009 a national strategy plan for prevention of unintentional injuries was published [23]. This plan highlighted that the lack of comprehensive data from national registries limited an evaluation of the overall effects of preventive initiatives.

Norway is divided into four regional health authorities (RHA) who are responsible for the establishment and continuation of specialized health care, including pre- and in-hospital medical care, research and education [182]. The prehospital emergency services consist of Emergency Medical Communication Centers (EMCC), land-based EMS, primary care physicians on-call and HEMS. In 1984 the first dedicated EMCC (equivalent of the Norwegian; Akuttmedisinsk Kommunikasjonssentral [AMK]) was established at Haukeland University Hospital. In 2015 there were 16 EMCCs in Norway staffed by special trained nurses and paramedics, which responds to the national medical emergency number 113 and co-ordinates EMS and HEMS [183]. A total of 524 land-based EMS were operating in 2014 [183]. In 1988 a National Air Ambulance Service (NAAS) was established. In 2014 the rotor wing–based part of NAAS consisted of 12 civilian HEMS, which are staffed by a pilot, anesthesiologist, and paramedic/rescuer providing advanced critical care to trauma patients. In addition six search and rescue helicopters staffed by anesthesiologists and operated by the Royal Norwegian Air Force perform regular ambulance missions. Furthermore, twelve fixed wing–based EMS operating in Norway perform a substantial number of emergency medical missions [184].

Since 1997 the Better and Systematic Trauma Care (BEST) foundation, has supported implementation of systematic trauma care according to trauma recommendations, including nation-wide simulation trauma team training [185]. In 2010 a total of 49 Norwegian hospitals received potentially severely injured patients, of which 48 had trauma teams and 46 had pre-defined trauma team activation criteria [109]. The National trauma report in 2007 reported that most hospitals were characterized by a low-volume of trauma patients, and only ten hospitals received more than 150 trauma patients/year [22].

2.7 Outcome after trauma

Traditionally, the impact of trauma is measured by risk-adjusted mortality rates. Mortality is an easily measurable and definite endpoint that allows comparisons among countries and different trauma systems [186]. However, using acute in-hospital mortality as the only variable can cause an underestimation of the total severity and impact of trauma. Many studies have shown that a majority of injury deaths occur before patients reach hospital [9, 76, 78]. Thus, to estimate population-based trauma mortality rates, central registries with accurate data on causes of death are required [105, 187, 188]. Further, Cameron et al. showed that whilst most trauma deaths occur in the immediate period after severe injury, the overall mortality of trauma patients remains higher in the following 10 years when compared with the non-injured population [189]. Davidson et al. also found a high rate of mortality occurring after discharge from hospital following major trauma [190]. Acute mortality as a sole outcome measure in major trauma may therefore be a too crude measure, capturing only a small proportion of the actual impact the health care service has on the trauma patients' quality of life.

Because most people who experience trauma, survive, other long-term outcome than mortality are relevant. Importantly, some injuries may be associated with low mortality, but significant loss of function or disability [186]. It is estimated that for each trauma death ten-folds of patients are permanently disabled [7]. Improved trauma care for these patients may improve outcomes, but not show any mortality benefit.

Survivors of trauma experience both considerable physical, socio-economic long-term and quality of life effects several years after injury [8, 191-193]. Many will have on-going pain, mobility problems in the short and medium term, problems undertaking usual activities, anxiety and depression [194, 195]. After brain injury, traumatic limb injuries cause the largest proportion of disability following injury [196]. This underlines the importance of long-term follow-up in order to evaluate trauma system performance and is crucial to make significant reductions in mortality and morbidity following injury [186]. In 2012 Gabbe et al. stated: *"The need to focus on capturing non-fatal injuries outcomes for evaluating trauma system and trauma centre care, and quantifying injury burden is well established. However, outcomes other than mortality are rarely addressed"* [140].

Robust outcome measures of trauma are needed to surveillance the impact that injuries have on public health, regionally, nationally and globally. Further, outcome measures form the basis for assessing the effectiveness of injury prevention programs and the quality of trauma care. Capturing health impact on a population basis is also important for health services design and delivery, resource allocation and future research [197].

2.7.1 Challenges measuring functional outcome

Collecting outcome variables other than mortality may infer considerable challenges with regards to financial, logistical and legal barriers [28]. Multiple tools are in use, most of which are complex and expensive to apply, few of which are universally accepted or have been validated in trauma care [186] [198]. There are currently no internationally agreed standard or robust approach to evaluate long term recovery and health outcome of trauma patients [198], and as many as fifteen hundred different process measures have been proposed as performance indicators for trauma systems [199].

Data collection can be time consuming, labor intensive and expensive [28]. Low-response rates in follow-up studies and questionnaires, cost and feasibility are all well-known limiting factors [200]. The patient population is highly mobile and long-term follow-up is generally considered difficult [186]. In 2012 the National Health Services (NHS) Outcomes Framework for England identified recovery from major injury as an important clinical area. The importance of data registry linkage to allow measurement of non-clinical outcomes such as return to work, maintenance of education and dependency of social benefit receipts was underlined [28].

2.7.2 Return to work

The ability to work can be seen as a surrogate of functional level, combining both physical and mental skills in performing complex and compound tasks. Non-participation in work or education has potential negative effects on health and economy, both for the individual patient and society [201-203]. In contrast, return to work (RTW) following illness or injury has a positive impact on health, and is considered central for the health and well-being of working age adults [194]. RTW has therefore been recommended as a long-term outcome measure [28].

Injuries needing hospital admission is found to have a large impact on health care use and on the ability in returning to work [194, 201]. A report from England reported that injuries to working age adults place a considerable burden on health services accounting for more than 10 % of general practice sick notes. Studies have found that between 28 to 68 % of those severely injured (ISS > 15), do not return to pre-injury level of work at 12 months post-injury [191, 204]. In studies following moderate to severe injuries (ISS > 9) a somewhat higher rate of approximately 50 % of RTW was observed [201, 205].

In a Norwegian study based on patient reported outcomes including a mixed cohort of minor and severe injuries, Tøien et al. found that return to work was 50 % after 3 months and 70 % after 12 months discharge from hospital [201]. Return to work after 3 months was independently predicted by low age, low ISS score and not needing ventilator support. Reducing one unit in the ISS increased the odds for RTW by 7 %. The study by Tøien et al had a significant number of patients lost to follow up and did not differentiate in their outcome measures based on level of injury severity [201].

3. Motivation for the thesis

As clinicians and researchers we constantly strive to provide our patients with the most updated and best medical care. Our care is based on in-house practices, eminence based wisdom, scientific evidence, clinical practice guidelines which all are adapted to patterns of injury and adjusted in accordance with available resources. The ways we improve is to constantly evaluate and assess whether our medical care is working appropriately and is in line with current best practice. In order to improve, we have to know the baseline values and benchmark level. If we are not knowledgeable about our practice, how can we measure change? How can we improve? How can we define the elements which potentially need to be addressed? And if we generally improve, how can we define which variables cause the most change?

In 2007 recommendations for a national trauma system was described [22]. Baseline values were very much based on estimations, and detailed structural and clinical data was lacking. My intention was to provide the needed baseline information. My motivation for this thesis has been to contribute to improve the care for wounded. As a physician there can be no greater motivation.

4. Aims of study

For patients with potentially severe physical injury treated in Norwegian hospitals, this thesis has the following aims:

4.1 Study 1 - National level

To study the current status of the Norwegian trauma system by identifying the number and the distribution of contributing hospitals and the caseload of potentially severely injured trauma patients within these hospitals at a national level.

4.2 Study 2 - Regional level

To give a detailed description of epidemiology, resource use, transfers and outcomes for all potential severely injured patients admitted to hospitals within a defined geographical area with a combination of acute care hospitals and a major trauma center, prior to the implementation of a formal trauma system.

4.3 Study 3 - Individual level

To describe the long-term consequences of trauma in a cohort including all patients with traumatic injury within a healthcare region, using return to work and receipt of medical benefits as primary outcome measures, and mortality as a secondary outcome.

5. Materials and methods

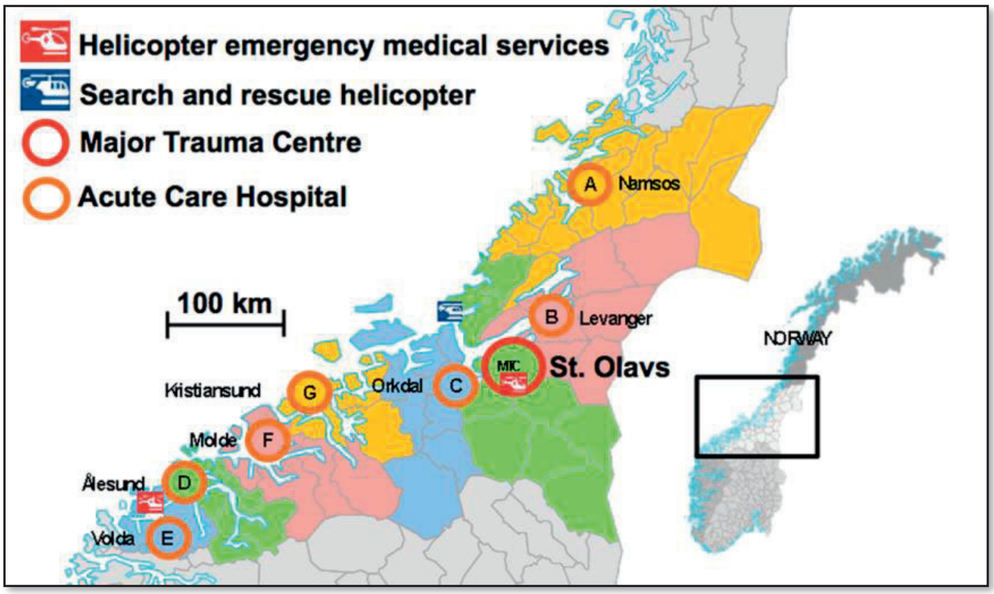
The three studies included in this thesis are all observational studies. In order to answer the questions posed, a cross-sectional study design was chosen in *study 1* and a cohort study design in *study 2 and 3*. No interventions were performed in any of the reported studies.

5.1 Study setting

In *study 1*, all Norwegian hospitals involved in the management of potentially severely injured patients were the subjects of investigation. The responsibilities of acute care hospitals were maintained by four regional health authorities. During the study period, all involved hospitals had predefined trauma teams, though the activation criteria showed considerable variation among hospitals [109]. Criteria describing trauma transfers from acute care hospitals to trauma centres were generally lacking [206]. The pre-hospital emergency service was well established and consisting of dispatch centres/emergency medical communication centres (EMCC), ground ambulances, on-call primary care doctors and air ambulances.

Study 2 and 3 were multicenter studies including patient data from hospitals within Central Norway (Figure 1); eight hospitals in *study 2* and seven hospitals in *study 3*. In *study 3*, one of the hospitals within the region did not have the possibility to provide the requested patient data. Central Norway is one of four regional health trusts in Norway, with eight hospitals receiving potentially severely injured patients at the time of study. This region covers an area of 56.385 km^2 with a total mixed urban/rural population of approximately 680.000 persons (at the time of study) [207]. St. Olav`s University Hospital in Trondheim served as the major trauma referral centre. Injured patients in need of special surgical treatment (neuro-, paediatric- and cardiothoracic surgery) or multidisciplinary intensive care medicine were admitted directly to the MTC or transferred from the other seven acute care hospitals (ACH) within the region. All hospitals had multidisciplinary trauma teams activated by predefined criteria and offered general surgical, orthopaedic and anaesthesia and intensive care medicine services, including x-ray and laboratory facilities. Computer-tomography (CT) was accessible in all institutions. Pre-hospital care was provided by approximately 90 paramedic manned ground-based emergency medical services (EMS), two paramedic and anaesthesiologist manned helicopter emergency medical services (HEMS) (Trondheim and Ålesund) and one military search and rescue (SAR) helicopter (Ørland). In addition two HEMS (Dombås and Brønnøysund) from other regional health care systems performed missions regularly within the region.

Figure 1 (Figure 1 in paper II) – Overview of hospitals involved in study 2 and 3



The map gives a regional overview of all seven acute care hospitals (A to G), the major trauma center (MTC) in Trondheim and regional air medical resources. The colored areas show each hospital`s uptake area. Volda (hospital E) hospital was not included in study 3.

5.2 Participants

5.2.1 Inclusion

In *study 1*, all Norwegian hospitals were identified through an overview of "National Health Institutions" provided by the National Directorate of Health [208] and were included in the study if they a) had an emergency department, and b) had 24-hour acute surgical services available.

In both *study 2 and 3* the same overall inclusion criteria applied. This included all patients who were admitted to any of the eight hospitals within the region and received trauma team attendance on (hospital) admission in the study period from 01.06.07 - 31.05.10. The time period was chosen due to the availability of patient data in all these hospitals from 01.06.07. In 2010 there was an ongoing regional discussion on possible structural changes and the data collection endpoint was chosen in order to provide a homogenous data collection throughout a defined time period.

In *study 3* the following additional inclusion criteria (compared to study 2) were applied: a) age from 16 to 65 years and b) the patient must be in work-related activity at the time of injury. Work-related activity at the time of injury was defined as work or educational activity in at least one of the two months prior to time of injury. This included those who (1) were registered students, and/or (2) had a registered employer, and/or (3) had an annual income of more than ~ € 10.581 (100.000 Norwegian kroner, exchange rate 16 July 2018). Patients who received medical or sickness benefits in the two months prior to injury were excluded.

5.2.2 Exclusion

In *study 1*, there were no study specific exclusion criteria as eligible hospitals were identified by a national public web page.

In *study 2 and 3*, patients who were pronounced dead prior to hospital arrival were excluded. In addition in *study 3* those patients not having a unique 11-digit Norwegian national identity number were also excluded. In *study 3*, one hospital did not have the possibility of providing the patients` national identity numbers and was thus excluded.

5.2.3 Definition of a trauma patient

In *study 1-3* we used the term "trauma patient" and "potential severely injured patient" as patients eligible for inclusion. We used these terms as the level of severity, using anatomical injury scoring systems (e.g. ISS and NISS), could not be determined until after in-hospital evaluation. Trauma patients were further defined as a patient receiving trauma team attendance/activation, according to each hospital's trauma team activation for patients with injuries potentially in need of rapid clinical evaluation and potential emergency interventions. Trauma teams were activated according to recommended criteria indicating physiological derangement, anatomical injuries and mechanisms of injury likely to cause severe injury [21]. However, the specific criteria varied among individual hospitals [109].

5.3 Data collection and sources

Study 1

In July 2012, a structured questionnaire was sent by electronic mail to each hospital's trauma coordinator. The questionnaire contained questions regarding the availability of a local electronic trauma registry and the number of trauma patients treated by trauma teams at their facility in 2011 (01.01.2011 – 31.12.2011). Where applicable, the number of patients who were transferred among hospitals was also included if this resulted in a trauma team activation (TTA). The hospitals with no system for registration of potentially severely injured patients were asked to estimate the number of patients, based on other sources of information (e.g., manual counting of trauma charts and/or number of performed CT trauma protocols). If the hospital did not respond or if the answers were inconclusive, a follow-up telephone interview was conducted with the hospital trauma coordinator. In addition information concerning time trends in the structural composition of hospital trauma care was obtained from an unstructured search of Norwegian scientific articles and white paper reports describing the Norwegian hospital acute care services.

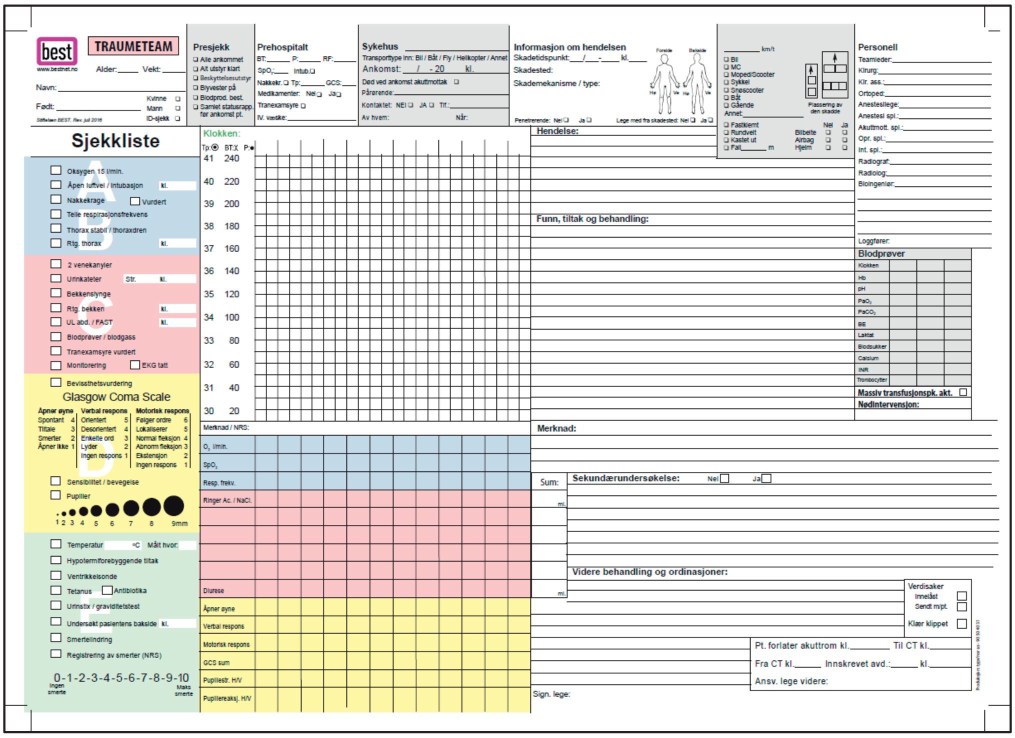
Study 2 and 3

From 01.06.07 all hospitals in Central Norway consecutively registered clinical patient data upon hospital admission of all patients who received trauma team attendance, using the same pre-defined patient chart recommended by the BEST foundation which contained both pre-hospital and in-hospital information (Figure 2). This registration was done consecutively and prospectively as part of daily clinical practice. Clinical data used in study 2 and 3, were extracted for study purposes.

Supported by the Unit for Applied Clinical Research at the Norwegian University of Science and Technology (NTNU) a web-based data entry form (WebCRF) was established to provide a feasible data collection platform adhering to standards of data safety [209]. The WebCRF allowed for continuous multicenter data collection and monitoring of collected data using a secure web interface solution. Following participating confirmation, each hospital was assigned a username and a password and hyperlink to the website was provided.

The clinical patient data contained in the WebCRF were pre-defined according to the Utstein template for uniform reporting of data following major trauma (chapter 5.3.1) [210]. In addition to data provided by the BEST chart, relevant information was obtained from the local EMCCs information system, EMS/HEMS reports and in-hospital electronic patient records. Data was recorded by a specially trained nurse at each study facility, using the WebCRF registration form [209]. Data was entered between May 2011 and May 2012 and the principal investigator was contacted in case of need for clarifications. This provided a collective set of de-identified clinical data from all institutions. The dataset was then manually searched by the principal investigator to identify records from patients treated at two or more hospitals. Scores in patients with duplicate records were calculated based on data provided by the last treating hospital.

Figure 2 - BEST journal chart


best
TRAUMETEAM
Presjekk
Prehospitalt
Sykehus
Informasjon om hendelsen
Personell
Sjekkliste
Klokken:
Hendelse:
Funn, tiltak og behandling:
Glasgow Coma Scale
Blodprøver
Massiv transfusjonspk. akt.
Nødintervensjon:
Merknad:
Sekundærundersøkelse:
Videre behandling og ordinasjoner:
Pt. forlater akuttrom kl.
Til CT kl.
Fra CT kl.
Innskrevet avd.:
Ansv. lege videre:
Sign. lege:
0-1-2-3-4-5-6-7-8-9-10

The BEST patient chart is used by all hospitals in Central Norway receiving potentially injured patients (reprinted with kind permission, BEST Foundation)

Study 3

In addition to clinical data provided in the data collection process described above in study 2, these variables were linked to individual data from national registers, using the unique 11-digit personal identity number given to all Norwegian citizens. Statistics Norway provided data on education from the National education database (NUDB), as well as data on income and demography. The Norwegian Cause of Death Registry, administered by the Norwegian Institute of Public Health, provided data on time and causes of death. Information on social insurance benefits and employment was obtained from the national event (FD-Trygd) database, provided by Statistics Norway [211]. These data contain detailed complete information on type of medical benefits, and entry and exit dates for the different benefits. Statistics Norway also provided information on annual income. The linkage process was done by Statistics Norway, and the identification key was kept by Statistics Norway, assuring anonymization of the linked data on the hands of the researchers. Patients were linked to individual data from national registers throughout 2014, allowing a follow-up time of up to six years (72 months) after trauma.

5.3.1 Utstein template for uniform reporting

The Utstein template for uniform reporting of data following major trauma was established to provide compatible definitions of common data variables, in order to allow for comparisons across trauma systems [210]. The template formed the basis for the clinical data collection in *study 2 and 3*. It originally consists of 36 core data variables, five exclusion criteria (first hospital admission more than 24 hours after injury, patients pronounced dead before hospital arrival, asphyxia and drowning) with NISS > 15 as inclusion criteria. A total of four original Utstein core data variables (INR, arterial base excess, time until first CT-scan and time until normal arterial base excess) were excluded as they were anticipated difficult to obtain [212]. Trauma team activation as a core variable was excluded as it was one of our inclusion criteria and two variables (pre-injury American Society of Anesthesiologists Physical Status [ASA-PS] classification and pre-hospital cardiac arrest) was excluded due to no formal system in capturing and/or interpreting this information. In addition we added four variables in our data set: hospital name, ISS, NISS and pre-hospital thoracic drainage. Pre-hospital drainage was defined as any intervention by any provider performed pre-hospital to remove air and/or fluid from the pleural space (i.e. chest drain, thoracostomy). We decided to apply these variables on all patients eligible for inclusion according to our study inclusion/exclusion criteria.

An overview of study variables and the quality of study variables used in *study 2 and 3* are displayed in appendix A and B.

5.4 Organization and education of data handlers

In *study 1* each hospital was identified using the list of National Health Institutions provided by the National Directorate of Health [208]. A trauma coordinator at each facility was identified using a contact person list provided by the BEST foundation network. These coordinators provided answers to the questions posed in this study.

In *study 2 and 3*, seven specially trained nurses were formally educated according to the Association for the Advancement of Automotive Medicine (AAAM) and using the AIS - Revision 2005 [166]. This also included education and familiarization in both the use of the ISS and NISS for injury severity grading. In addition each trauma coordinator underwent familiarization with the Utstein template for uniform reporting of data following major trauma

[210] and practical training in the use of the WebCRF solution [209] prior to commencement of data collection.

5.5 Outcome variables

5.5.1 - Study 1

The outcome variables in this descriptive study were: 1) the number of hospitals receiving potential severely injured patients nationally 2) the number of potential severely injured patients in each hospital and 3) if a local electronic trauma registry was available in each facility. In addition a search of Norwegian scientific articles and white paper reports was performed to assess the number of hospitals admitting potential severely patients over time (1988-2011).

5.5.2 - Study 2

The outcome variables in this descriptive study were categorized into five main categories: 1) population description (total frequency of patients and per hospital, sex, age, dominating type of injury and mechanism of injury), 2) injury severity (ISS, NISS, AIS $\geq 3_{\text{body region}}$ and frequency of patients with physiological derangement), 3) patient transfers (frequency of patients transferred between hospitals) 4) resource use (length of stay [LOS] in hospital, number of days on ventilator, number of key in-hospital emergency surgical interventions, type of transportation, frequencies of performed pre-hospital intubation and pre-hospital thoracic drainage and 5) outcome (Glasgow Outcome Scale [GOS] and mortality 30 days after injury).

Dominating type of injury was defined as blunt, penetrating or unknown [210]. ISS, NISS and AIS are described previously. Physiologic derangement was defined as pre-hospitals values of one or more of the following values: systolic blood pressure < 90 mmHg, respiratory rate (breaths per minute) < 10 or > 30 or Glasgow Coma Scale (GCS) ≤ 8. The categories "Head injury", " Spinal injury", "Thoracic injury", "Abdominal/pelvic injury" and "Extremity injury" included patients with an AIS ≥3 injury in the respective region. An AIS score ≥ 3 is defined as a serious injury [166].The first key in-hospital emergency surgical interventions were defined as immediate lifesaving surgical interventions according to the Utstein template [210], within the first 24 hours of admission. The GOS is a 5-point ordinal outcome scale ranging from 5 to 1 (5 = good recovery, 4 = moderately disability, 3 = severe disability, 2 = persistent vegetative state, 1 = death).

5.5.3 - Study 3

The primary outcome measures were 1) receipt of medical benefits and 2) time to return to pre-injury work level. These were constructed by combining extracted information on employment status, reception of medical benefits, educational status and income from each calendar month during follow up and also for the two years preceding the injury. Secondary outcome measures were mortality within 30-days and mortality during the follow-up period. Medical benefit receipt included all sickness and disability benefits. Return to pre-injury work level was defined as return to the same or higher level of activity as compared to two months preceding the injury (pre-injury work level). Work activity level was assessed using three groups: full-time workers > 30 hours/week or earned > ~ € 31.746/year, part-time (large) workers 20-30 hours/week or earned > € 21.164 - 31.746/year or part-time (little) workers 0-20 hours/week or earned > € 10.581 - 21.164 /year. The term "workers" included both persons with full- or part-time employment. Students could not be included in the return to work activity analyses because the educational data does not provide the necessary level of details to identify monthly changes in status.

5.6 Statistical analysis

Data analysis for *study 1 and 2* was performed using statistical software Statistical Package for the Social Sciences (SPSS) version 21.0.0.2 (IBM Corporation, released 2012. SPSS Statistics for Windows, IBM Corporation, Armonk, NY, USA) and version 22 (IBM Corporation, released 2015. SPSS Statistics for Windows, IBM Corporation, Armonk, NY, USA). In *study 3* Stata Statistical Software version 14 (StataCorp, College station, TX) was used for all statistical analysis. The presentation of the results are according to "Strengthening the Reporting of Observational Studies in Epidemiology" (STROBE) guidelines for observational studies [213].

5.6.1 Descriptive statistics (Study 1-3)

Descriptive characteristics were presented as means, medians with inter-quartile range (IQR), and as absolute numbers, percentages and ranges where appropriate. Student T-tests were used to compare mean values of continuous variables between two groups, whereas Pearson's chi-squared test was used for comparison of categorical variables. Statistical significance level was set at $p<0.05$.

5.6.2 Multivariable analysis (Study 3)

The associations of trauma severity (three groups of ISS severity level – minor (0-8), moderate (9-15) and severe (> 15), the presence of a severe head injury (AIS $_{head} \geq 3$)) with the different study outcomes (receipt of medical benefits, return to pre-injury activity level, and death) were assessed in separate analyses. All patients were followed with monthly registrations of receipt of medical benefits (yes/no) from two years before trauma up to six years (72 months) after trauma, censoring observations in the case of death, emigration, old age retirement or 31.12.2014 (last available date for registry data). The two-year period before injury was included in order to provide a comparison "baseline" for each group. We used information from these monthly registrations to construct dichotomous variables of benefit receipt during three-month periods - in total 8 periods before injury and 24 after injury. Longitudinal logistic regression models (general estimating equations) were used to explore the association between injury characteristics and benefit receipt, including time periods (32 three-month periods/quarters) as a categorical variable in the models. An interaction term between the time variable and trauma severity was included to allow for different trajectories of benefit receipt over time for patients with different injury severity. All analyses were adjusted for sex, age and educational level. Estimates from the population-averaged regression analyses were used to calculate predicted level of benefit receipt with 95% confidence intervals, according to time and injury severity (for graphical representations). The analyses were repeated for subgroups according to pre-injury activity (full-time workers and students).

For the "time to return to work" analyses, patients were followed from the first month after injury to the first month with "return to pre-injury work activity level", disability pension, death, emigration, old age retirement or January 2015 (whichever came first), within a time frame of 72 months after injury. Only patients actually in work prior to injury were included in this analysis, n= 908. For mortality analyses, all patients were followed from the day after trauma to the date of death, emigration or 31.12.2014, whichever came first. Kaplan-Meier survival analyses were performed to estimate time-to-event (return to work and death) for patient groups according to injury severity. For multivariable analyses, we used Cox proportional hazard regression analyses (adjusting for sex, age and educational level) to compare groups according to injury severity estimating hazard ratios (HRs) with 95% confidence intervals (CIs).

5.7 Ethical approvals

Study 1: The Regional Committee for Medical and Health Research Ethics was informed about the study and decided that formal ethical approval was not required (REC Central Norway 2014/763).

Study 2: The study was approved and the need for patient consent was waived by the Regional Committee for Medical and Health Research Ethics (REC South East B Norway, 2010/2022b).

Study 3: The study was approved and the need for patient consent was waived by the Regional Committee for Medical and Health Research Ethics (REC South East B Norway, 2015/1582). This study was also registered in ClinicalTrials.gov (NCT02602405).

5.8 Financial support

During the completion of these studies, no study participants, co-workers or co-authors received any financial benefits or payments. The principal investigator (Oddvar Uleberg) received salary from St. Olav`s University Hospital, Trondheim, Norway, during the study period as a clinical member of staff at the Department of Emergency Medicine and Pre-hospital Services. This salary was partly funded by the Norwegian Air Ambulance Foundation (2016-2018). Study 2 and 3 were supported by grants, whereas the funders had no involvement in study design, data collection, data analysis, data interpretation, or writing the manuscripts.

Study 2: The study was funded by grants from The Norwegian Medical Association – The fund for quality and patient safety (reference 10/5223) and The Health Trust of Sunnmøre (reference 11 FU 56-10).

Study 3: The study was supported by St. Olav`s Hospital, University Hospital, Trondheim, Norway (grant number 15/1164-36/GRLO) and the Department of Circulation and Medical Imaging, Faculty of Medicine and Health Sciences, NTNU, Norwegian University of Science and Technology, Trondheim, Norway.

6. Results – Summary of papers

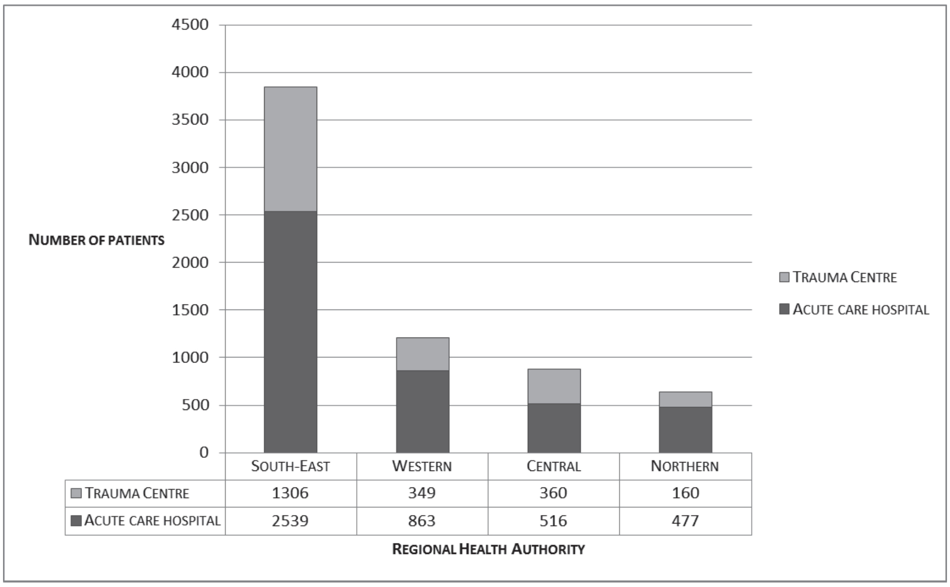
6.1 Study 1 – Paper I

Norwegian trauma care: a national cross-sectional survey of all hospitals involved in the management of major trauma patients.

Aims: to study the current status of the Norwegian trauma system by identifying the number and the distribution of contributing hospitals and their caseload of potentially severely injured trauma patients.

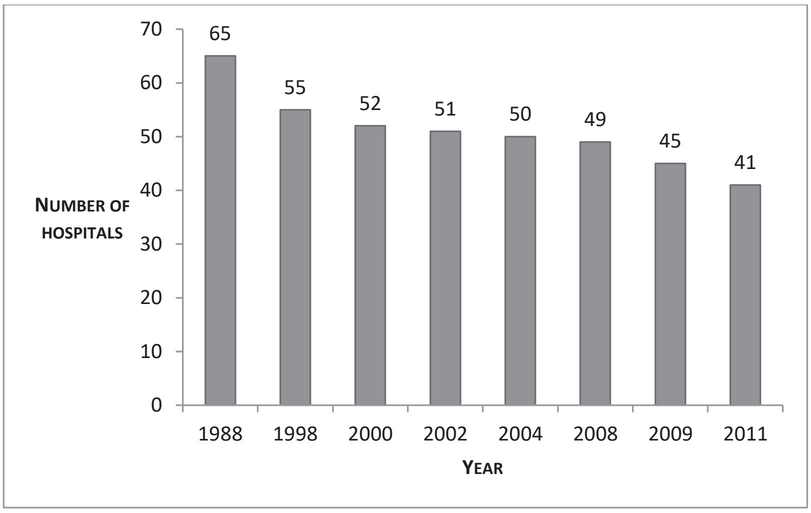
Results: Forty-one hospitals responded and were included in the study. A total of 6,570 trauma patients were admitted to four trauma centers and 37 acute care hospitals from 01.01.2011 – to 31.12.2011. Of these, 4,722 (72 %) were exact figures based on the data in the trauma registries and 1,848 (28 %) were estimated from other sources. Thirteen hospitals reported the existence of a local electronic trauma registry. One third of the patients (n = 2,175; 33 %) were admitted to a trauma center, and two-thirds (n = 4,395; 67 %) were admitted to acute care hospitals (Figure 3). The relative contribution from trauma centers in different regions ranged from 25 % (Northern RHA) to 41% (Central RHA). Corresponding figures in Western RHA was 29 % and 34% in South-East RHA, respectively. More than half of the hospitals (52.5%) received fewer than 100 trauma patients.

Figure 3 (Figure 1 in paper I) - Distribution of patients per region and type of hospital



The national rate of trauma admission was 13 per 10,000 inhabitants. There was a 37 % (from 65 to 41) reduction in the number of hospitals involved in acute trauma care between 1988 and 2011 (Figure 4).

Figure 4 (Figure 2 in paper I) - Number of Norwegian hospitals receiving trauma patients



Conclusions: In 2011, hospital acute trauma care in Norway was delivered by four trauma centers and 37 acute care hospitals. Many hospitals received a small number of potentially severely injured patients and only a few hospitals had an electronic trauma registry. Future development of the Norwegian trauma system needs to address the challenge posed by a scattered population and long geographical distances. The implementation of a trauma system, carefully balanced between centers with adequate caseloads against time from injury to hospital care, is needed and has been shown to have a beneficial effect in countries with comparable challenges.

6.2 Study 2 - Paper II

Trauma care in a combined rural and urban region: an observational study

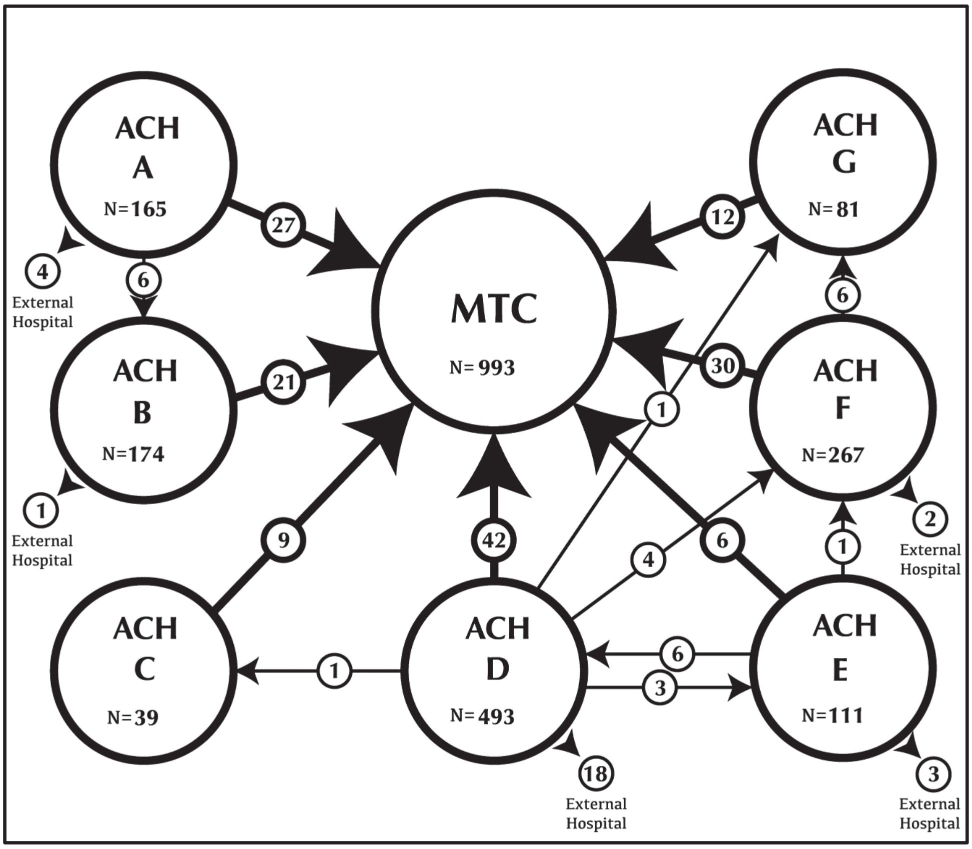
Aims: to study the epidemiology, resource use, transfers and outcomes for all potential severely injured patients admitted to hospitals within a defined geographical area with a combination of acute care hospitals and one major trauma center prior to implementation of a formal trauma system.

Results: A total of 2323 patients were included, of which 1550 (67 %) were men. Blunt trauma caused 97 per cent of all injuries, and the majority of injuries were transport related (69 %) or due to falls (19 %). ACH received 1330 patients and delivered definite care to 85 % of these. Only 329 (14 %) of all patients were major trauma of which 134 (41 %) were initially received at an ACH. Nine per cent (n=203) of patients were transferred between hospitals (Figure 5). After inter-hospital transfers, 79 % (n=259) of all major trauma patients received definite care at the MTC. Helicopter emergency services admitted 52 % of major trauma and performed 68 % of inter-hospital transfers from ACH to MTC.

The incidence of major trauma patients was ~2 per 10.000 person-years. For major trauma patients, 155 (47 %) showed signs of physiological derangement. The major trauma patients who were admitted to an ACH and not transferred were older and had a lower ISS than those admitted directly or transferred to the MTC. At hospital discharge 1849 patients (79 %) had a good neurological outcome GOS = 5). Forty-eight (2 %) of the admitted patients died during the first 30 days after trauma.

Conclusions: In a region with a dispersed network of hospitals, geographical challenges, and low rate of major trauma cases, efforts should be made to identify patients with major trauma for treatment at a MTC as early as possible. This can be done by implementing triage and transfer guidelines, maintaining competence at ACHs for initial stabilization, and sustaining an organization for effective inter-facility transfers.

Figure 5 (Figure 2 in paper II) - Overview of patient flow among hospitals



The flow chart shows transfers between acute care hospitals (ACH) and the major trauma center (MTC). The number inside the circles gives the numbers of direct hospital admissions. External hospitals are hospitals located outside the region.

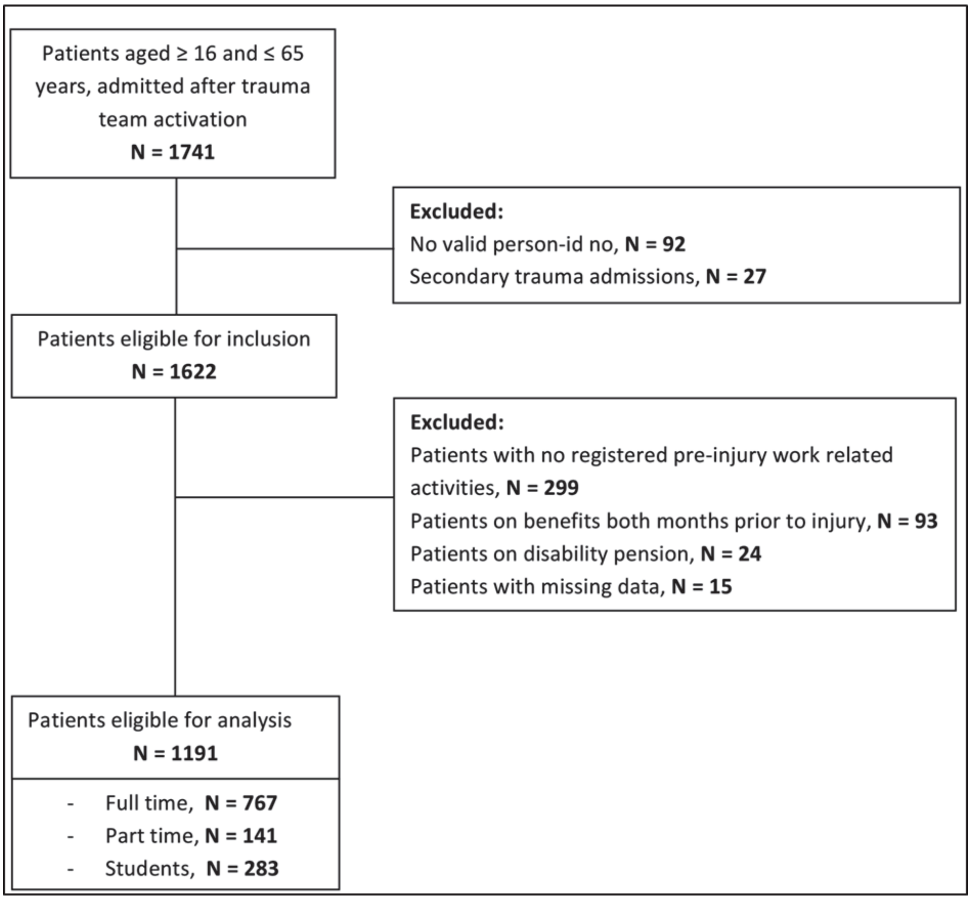
6.3 Study 3 - Paper III

Population-based analysis of the impact of trauma on longer-term functional outcomes

Aims: To describe the long-term consequences of trauma in a cohort that included all patients with traumatic injury in a healthcare region, using return to work and receipt of medical benefits as primary outcome measures, and mortality as a secondary outcome.

Results: A total of 1191 trauma patients with registered pre-injury work related activity were included in the study (Figure 6). Seventy per cent were males (n = 828) and the median age was 27 years (IQR 19 – 45). Sixteen percent (n = 193) of the patients were severely injured (ISS > 15) and nine percent (n = 109) had a severe head injury (AIS $_{head}$ ≥ 3). Among the severely injured, forty-four per cent (n=85) had a severe head injury.

Figure 6 (Figure 1 in paper III) - Overview of patient inclusion



Five years after injury, the three-month prevalence of medical benefits among those still alive and of working age (n = 993) was 15.6 % among workers with minor injury, 22.3 % in moderately injured and 40.5 % in workers with severe injuries. Corresponding figures in students were; 9.1 % minor, 19.4 % moderate and 18.9 % severe, respectively. Patients with severe injury and severe head injury received more often medical benefits during the entire follow-up (Figure 7). A high level of medical benefit receipt was observed in all severity groups in the time period immediately after the time of injury, which declined to a steady state situation from one year post-injury and throughout the follow-up period (Figure 7).

Figure 7 (Figure 2 a-d in paper III) – Predicted probabilities of receiving medical benefits after injury

Predicted probabilities of receiving medical benefits after injury. Predicted probabilities (dashed line) with 95% confidence intervals (colored areas) of sickness/disability benefits before and after injury (time of injury marked with a black line at 0 years), according to injury severity score (ISS) and severity of head injury. Benefits were assessed in three-month periods (benefit or no benefit) and estimates were calculated from population-averaged logistic regression models.

A total of 908 patients worked prior to injury, of which five patients were excluded (four died and one retired) before start of follow-up, leaving 903 patients for final analysis. Of these, 818 (91%) patients returned to work after injury within the follow-up period. Median time to return to work in those with minor, moderate and severe injuries was 1, 4 and 11 months, respectively. Median time to return work in patients with and without severe head injury was 11 and 2 months, respectively, with an adjusted HR of 0.44 (95% CI 0.33 – 0.58) for those with severe head trauma. A total of 1191 patients were eligible for the mortality analyses of which 12 (1.0 %) patients died within 30-days and an additional 17 (1.4 %) patients died during the subsequent follow-up period. Severe injuries were associated with an increased risk of dying (adjusted HR = 11.54 (95% CI 4.49 – 29.66), compared to minor injuries. Similar findings were observed in patients with severe head injury (adjusted HR = 15.02 (95% CI 7.04 – 32.05), compared to those with a no severe head injury.

Conclusions: This study demonstrates that patients experiencing minor, moderate and major trauma initially received high levels of medical benefits; however, most recovered within the first year and resumed preinjury work activity. Patients with severe trauma were more likely to receive medical benefits and have a delayed return to work.

7. Discussion

7.1 Methodological considerations

7.1.1 Study design

The main objective of this thesis and the included studies was to provide a descriptive overview of the trauma system and trauma epidemiology on a national, regional and individual level. We addressed the research questions raised by applying various observational study designs to all three studies included. Observational studies are not designed to explore causal effects, but can describe the associations between the measured variables and outcomes [214]. In *study 1*, information was gathered at one point in time from multiple Norwegian hospitals using a cross-sectional study design. Cross-sectional studies allow for assessment of disease prevalence but not of disease incidence, as risk or rate estimations needs follow-up over a specified time period [215].

For *study 2 and 3*, a multicenter cohort consisting of all injured patients in a region of Norway during a three-year period was established. Information on individual patients was gathered retrospectively, allowing for descriptive characteristics of key issues from all phases of the trauma care chain. Cohort studies are generally defined as *"any designated group of individuals who are followed or traced over a period of time"* [215]. The intention of a cohort study is to measure the incidence of one or more specific diseases during the period of follow-up, usually with the objective of comparing incidence rates for two or more differentially exposed groups [215]. In *study 3*, a cohort study design was used in order to follow trauma patients over a longer time period and to assess the associations between injury severity and functional outcomes. The lack of a non-injured ("control") group in *study 3* was a limitation of this study, as this would have allowed for a better assessment of excess risk of long-term functional outcomes for trauma patients.

7.1.2 Precision (lack of random error)

Precision is a measure of lack random error, and can been seen as an error with statistical fluctuations in either direction, affecting the precision of our results after removing systematic errors [215]. Confidence intervals are used to interpret the effect of random error. A confidence interval of 95 % is most commonly chosen, reflecting that this interval will contain the true population value in 95 % of the time. This measure will largely be affected by the prevalence of outcome and the magnitude of sample size. Discrete outcomes and small sample sizes might cause wider confidence intervals, indicating reduced precision and larger effects of random error [215] [216].

Statistical associations were not assessed in the study samples in *study 1 and 2*. One of the primary aims in *study 3* was to assess the statistical association between injury severity and longer term impacts of trauma. The cohort in *study 3* was fairly large, but analyses regarding the smaller group of severely injured yielded less precise estimates with wider confidence intervals. Though using a large number of repetitive measurements over a long period of time, the overall trends over time did not seem to differ.

7.1.3 Validity (lack of systematic error)

Internal validity refers to how appropriately the study cohort characterizes the source population, e.g. does the study measure what it is supposed to measure. External validity refers to the ability to apply the outcomes of a study to other populations, settings or patients [217]. In observational cross-sectional and cohort studies internal validity is generally considered low, whereas the external validity is considered high [218]. This relates to the general inability to control exposure and outcome variables prior to data collection, whereas experimental studies (e.g. RCTs) display a high internal validity and low-to-moderate external validity [218]. In *study 1*and *2,* the study objectives were purely descriptive without the intention to infer causation among exposure and outcome variables. Also, in *study 2*, this study was not designed to compare outcomes different levels of hospitals. Such a comparison would be affected by several selection biases (e.g. weather, distance to hospital, triage decisions at the scene of accident) not accounted for in the study design.

Study biases are forms of systematic errors which can be introduced into any stage of a study and affect the accuracy of measurements observed and/or performed. In general, biases can be grouped into three general categories: selection bias, information bias and confounding [215]. Such bias may also impact the internal and external validity of the study results.

7.1.3.1 Selection bias

Selection bias refers to potential errors which develop during the processes to select subjects for study participation. In all studies (*study 1-3*) included in this thesis, there were defined inclusion and exclusion criteria.

Study population

In *study 1* the aim was to identify the number and distribution of contributing Norwegian hospitals and the caseload of potential severely injured patients in 2011. An overview of these hospitals was provided by the National Directorate of Health [208]. As potentially severely injured patients were commonly provided emergency care by public hospitals, the likelihood of patients receiving trauma care elsewhere than in these designated hospitals was low. The study observed a 37 % reduction (from 65 to 41) of hospitals involved in the care of these patients from 1988 to 2011. This structural process might therefore have allowed for a number of trauma patients unaware of local hospital capability (e.g. no trauma care), not handled by EMS and injured in the proximity of a local hospital seeking health care in these hospitals and thereby not included in this study. Although this is likely to present as a rare event, it may lead to and underestimation of patients with potential severe injury treated in designated Norwegian ACHs and MTCs. Another limitation is that the number of trauma patients in *study 1* may be overestimated because some patients were initially received at ACHs and then later transferred to MTCs for definitive care.

In *studies 1-3* we used the term “potential severely injured patient” in patients who received trauma team attendance and were eligible for study inclusion. These patients were likely to have sustained severe injuries according to the criteria defined in the hospital`s TTA protocols. Prior to commencement of *studies 1-3* no regional or national systems existed for capturing injured patients admitted to hospital without TTA. Therefore, the use of TTA was defined as the main inclusion measure. Previous Norwegian studies have observed a low threshold for the use of TTA with rates of overtriage from 71.6 % to 78 %, indicating an overuse of this hospital resource [108, 219]. Thus, the probability of missing patients with potential severe injury has been regarded as low. However, the use of trauma team activation as inclusion criteria in *studies 1-3*, could have introduced some degree of selection bias and underestimation of the true number of potentially severely injured patients. Patients who were admitted to hospitals after sustaining injuries and who did not receive trauma team attendance, would not be included in the study although some might have sustained some degree of traumatic injury. Previous reports have described rates of undertriage from 10 to 19 per cent [108, 219, 220], but as shown by Uleberg et al. [108] the majority of undertriaged patients were hospitals transfers. In *study 2 and 3*, this element was taken into account as a multicenter design was applied including all hospitals within the region and thereby reducing the likelihood of transferred patients not being included. A further variable introducing selection bias to the inclusion process, might be due to differences in TTA criteria among Norwegian hospitals [109]. This could potentially cause regional differences, over- or underestimation of hospital caseload due to different definitions used to identify trauma patients. Recent publications also indicate that increasing age is associated with increased likelihood of undertriage [221, 222]. An underestimation of the true number of potentially severely injured patients is therefore possible, but was still regarded as low. The results in *study 3* would not be affected due to the age inclusion criteria, only including patients from 16 to 65 years of age.

In study 3 we included only patients aged 16 to 65 years with the unique national 11-digit personal identity number, and who were in work-related activity at the time of injury according to study definition (Figure 6). This strict inclusion procedure was made in order to answer the research questions posed, but is likely to have provided a study cohort considered healthier than the average trauma population. A further limitation of the study is that in order to address the capability of returning to pre-injury activity level injury, those with no work or educational activity before trauma were not included. We have, therefore, no information of the social trajectory after trauma in this group of patients.

Exclusion

During *study 2 and 3* there was no formal registry or system to ensure data capture on pre-hospital deaths, therefore these studies did not include those patients who died prior to hospital arrival. Previous reports have described the rate of pre-hospital deaths ranging from 69 % to 78 % of trauma deaths [6, 9]. The use of data from the Norwegian Cause of Death Registry to identify pre-hospital trauma deaths was considered, but not performed as previous investigations have reported chance of misclassification and unspecific cause of deaths [223]. This may have led to lower mortality rates of mortality in *study 2 and 3* than comparable studies. In *study 3* the number of hospitals including patients was reduced from eight to seven, compared to *study 2*. This was due to one hospital did not have the possibility to provide the requested patient data including the 11-digit national identity number. Baseline characteristics of the included hospitals in *study 2* did not show any substantial differences comparing this one hospital to the other seven with regards to composition of trauma severity within the trauma cohort.

Loss to follow-up

In *study 2*, for foreign patients national identity numbers were not available, leaving non-Norwegian patients without the possibility of follow-up for 30 day mortality after discharge from hospital. However, we considered this bias limited both due to a low number of foreign patients and due to that patients discharged from hospital are expected to live for 30 days. Strength in *study 3* was the linkage with national registries, with no patients lost to follow-up and with complete registrations of primary and secondary outcomes up to 72 months post trauma.

7.1.3.2 Information bias

Information bias describes the possibility of systematic errors which occurs when the collected study information is wrong or misclassified [215]. Data collected retrospectively from registries might have lower reliability as they were originally designed for logistical and administrative reasons and not for study purposes. Data quality from retrospective studies is generally considered of lower quality due the possibility of information not recorded at the time of the incident, increasing the possibility of missing data and changes in data sampling procedures and variable definitions over time, information which may be unknown to the researcher.

In *study 1*a structured questionnaire containing two questions were sent to each hospital`s trauma coordinator. The questions of availability of an electronic hospital trauma registry and the number of TTA in a single year (2011) were seen as clearly defined questions with small risk of misinterpretation and response bias. A potential limitation is that collected data was primarily obtained from one contact person at each hospital. The responses were not validated, e.g., by interviewing other persons within the same hospital. An unstructured search of Norwegian scientific articles and white paper reports was performed to identify the number of Norwegian hospitals receiving trauma patients. Some papers might have been undetected during this search, though the reports found showed an unambiguous trend towards fewer hospitals from 1988 to 2011 (Figure 4).

In *study 2 and 3* the use of clinical patient data was imperative to answer the research questions. As part of clinical practice, patient data was collected consecutively and prospectively from the time EMCC responded to the emergency call and further during pre- and in-hospital treatment. For study purposes the data was retrospectively extracted by specially trained nurses using the variables defined in the Utstein template for uniform reporting of data following major trauma [210]. The principal investigator was available to clarify potential misunderstandings. The Utstein template provided compatible definitions of common data variables, in order to allow for comparisons across trauma systems and formed the basis for the clinical data collection in *study 2 and 3*. This method represents a strength of these studies and provided a high response rate with good data quality in the majority of clinical data variables in *study 2* (Appendix A) and *study 3* (Appendix B). The strict inclusion criteria, the use of commonly used and attainable variables according to an international defined template, standardized collection of study data and education of data handlers reduced the possibility of differential measurement errors and misclassification.

In *study 3* clinical patient data was linked to national registries on education, income, causes of death and the national event database with records of receipt of medical benefits. Use of register data, minimizes the risk of information bias, compared to patient reported outcome measures [224]. In addition national registries reduce the rate of non-responses, provide complete follow-up and provide exact entry and exit dates of incidences, which is seen as a challenge in studies based on other sources [225, 226]. The linkage provides high data accuracy and quality due to the use of the unique identification number given to all Norwegian citizens. However, registry data also presents some limitations. Some variables like education and income were available on a yearly basis only, yielding less detailed information on the outcomes. Also, educational status provided information on registered status, but not of whether an individual actually attended school or not. In general, information regarding receipt of benefits from the event database covers the entire Norwegian population. However, information on each different benefit was available only for persons eligible for that specific benefit and eligibility criteria differ between benefits. We therefore chose only to include patients for which benefit eligibility could be established, and performed separate analyses for students, who are less eligible for sickness benefits. Lastly, there is no good single measure in the registry data of actual work participation, and the study variable of participation in a work-related activity was constructed on the basis of several registries. All these limitations in the registry data may lead to misclassification, both when defining inclusion criteria and in the outcome assessment. However, this misclassification is considered to be non-differential, and thus a less likely source of biased estimates.

7.1.3.3 Confounding

Confounding occurs when an association between exposure and outcome is mixed with the effect by the presence of one or several other variables [215]. This effect is seen as a challenge in observational studies, where selection bias and confounding can give under- or overestimates of the actual effect of an event or exposure [227]. *Study 1* and *2* were designed as purely descriptive studies in which we did not perform any adjustments of potential confounders.

In *study 3* age, sex and educational level were seen as potential confounding factors and adjusted for by using statistical regression models. Underlying mental and somatic health conditions (e.g. diabetes, epilepsy, depression, drug abuse) and social adversity are other potential confounding factors as they may act as common causes of both being more severely injured and long-term outcomes (e.g. survival, medical benefits and work related activity), and which may contribute to an overestimation of the impact of injury severity. In order to minimize such bias only patients with documented work related activity and not on long-term medical benefits were included. Such bias is considered of less relevance for the abrupt increase in benefit receipt directly after the injury, but could be of importance later during follow-up. Differences in functional outcome between injury severity groups many years after injury must thus be interpreted with caution, as these differences could reflect composition of the groups.

7.1.3.4 External validity

In *study 1*, comparison of results regarding national number of major trauma patients with similar population sizes in Scotland and Finland displayed comparable results. From *study 2*, similar results are likely to be found in mixed urban-rural health care regions, with scattered population, dispersed network of hospitals and predominantly blunt trauma. Comparable results from *study 3* applied to other populations and investigating receipt of medical benefits and return to work following trauma is substantially dependent on the nature of the existing benefit system. Although one of the major findings in *study 3* is the long-term impact of receipt of benefit in all severity groups, the externalization of these findings may not be present in settings without a national insurance scheme. In *study 2 and 3* we applied a multicenter study model including several hospitals. This may also increase the generalizability of the results, incorporating the differences observed between different hospitals and the patient demographics within an entire region.

Although the results found in these three studies can be generalized to trauma systems and patients in comparable settings, it is important to highlight that the patients included still only represent a sample of the total magnitude of patients subjected to physical trauma. Thus, we have no data on other important groups of trauma patients who experience substantial impact on their health despite relatively minor anatomical injuries, such as single hip fractures in older people [228] and patients with complex regional pain syndrome [229]. On an annual basis 10 % of the Norwegian population is estimated to sustain injury which needs assessment at some level of healthcare of which 36000 sustain permanent functional impairment, 1200 disability pensions and approximately 2500 persons die as a result of accidents and violence, including self-inflicted injuries [8]. A Norwegian study by Lund et al. estimated that for every death 10 patients were permanently disabled, 30 patients hospitalized and another 250 patients medically treated [7]. Similar results are described in international literature [2, 230]. These other studies do not limit the conclusions found in *studies 1 to 3*, but remind us to interpret our findings with caution.

7.1.7 Ethical considerations

All studies were performed in accordance with the World Medical Association Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects [231]. The *studies 2 and 3* involved the use of patient sensitive data, which was collected locally and by national approved health registries according to The Health Research act of Norway [232] and institutional approval. No interventions were performed in these studies. We argued that in these studies the number of patients was considered large, extended over a longer time-period (*study 2*: 2007-2010 / *study 3*: 2005-2014), covering a substantial geographical area and with several institutions involved. The patients were also to be considered to have a high total degree of morbidity and mortality. For these reasons, it was considered not possible to perform *studies 2 and 3*, based on collection of informed consent from all involved patients. *Studies 2 and 3* were approved and the need for patient consent was waived by the Regional Committee for Medical and Health Research Ethics.

Injuries affect patients and our society both with substantial individual and socioeconomic consequences. Providing benchmark knowledge and describing new ways of measuring the impact and consequence of injury by combining national registry data and clinical patient data are underlined by national health authorities [8, 23, 178]. On these grounds we reasoned that the beneficial effect of these studies would outweigh the possible individual negative consequences described in § 35 in The Health Research Act of Norway [232].

7.2 Discussion of main findings

7.2.1 Maturity of the trauma system

The main objective of the included studies was to establish baseline knowledge of the current system in order to evaluate its maturity. Before the initiation of our studies a Norwegian national trauma report concluded that no formalized trauma system structure had been fully implemented [22]. Though several important elements of a trauma system had been implemented as part of national health services (i.e. injury prevention, established EMS/HEMS), the trauma system could still be described as an immature trauma system [22]. According to the WHO Maturity Index Trauma Systems the maturity of a trauma system can be divided into four levels, from Level I (lowest level) to Level IV (highest level) by evaluating four categories: prehospital trauma care, education and training, facility based trauma care and quality assurance [233]. In our *study 1* we observed that a total of forty-one hospitals were involved in the care of potentially severely injured patients and two-thirds of patients were admitted to local hospitals. Population adjusted rates showed an evenly regional distribution of patients, though with regional differences in admission rates between local hospitals and MTCs. Only thirteen hospitals (32 %) had a local electronic trauma registry. In *study 2* we described a well-established prehospital emergency system, all hospitals had trauma teams, TTA activation protocols, but no hospitals had established inter-hospital transfer criteria. Incorporating these findings into the WHO Maturity Index Trauma Systems, the trauma system at a national and regional level at time of study could be categorized as a partially immature system, with most potential for improvement within facility based trauma care (Level II) and quality assurance (Level II). Prehospital trauma care (Level IV) and education and training (III) could also benefit from increased standardization. The low rate of severely injured and few deaths following trauma observed in *study 2 and 3*, is likely to be caused by incorporation of several elements highlighted in trauma recommendations [21] prior to formal trauma system establishment. Since the initiation of *study 1 - 3*, one of several steps to trauma care was to establish The Norwegian National Advisory Unit on Trauma in 2013 [234]. The Norwegian National Trauma Registry was established in 2005, but first started data collection from hospitals in 2014/2015 [235]. Results from *study 1 – 3* show that questions regarding centralization of trauma services, rurality, low patient volume and time criticalness of severe trauma are important characteristics of the Norwegian trauma panorama and need consistent attention.

7.2.2 Centralization

The purpose of a trauma system is to provide an organized and systematic approach for all those injured, and thus provide a timely and adequate response to potential severe injury [20, 86]. Arguments for centralization are the need for a sufficient patient volume to provide adequate quality of care and the likelihood of capable on-site medical competence in larger trauma centers. Following the evolution of trauma care, the introduction of the all-encompassing inclusive trauma system has proven more valid for the majority of settings apart from the densely populated urban areas [66]. However, in a European setting the evidence for increased centralization is weak and the data is still sparse [155].

In *study 1* we observed a 37 % (from 65 to 41) reduction in the number of hospitals receiving trauma patients between 1988 and 2011. The exact reasons for this decrease were not further explored in our study, but are likely to be due to national, regional and local needs as well as political, economic and medical aspects. The acute care hospitals received two thirds of all trauma patients and made a substantial contribution within the Norwegian trauma system. Comparing the four different health regions we observed an uneven admission rate between the regions in the number of patients transported directly to the trauma centres versus acute care hospitals. These differences may be caused by different organizational structure, geography and number of contributing hospitals. In *study 2* more than half of all patients were received at ACHs, for which they delivered definite care to eighty-five per cent. Only nine per cent of included patients were transferred among hospitals.

Several studies have reported that a large number of patients are initially managed outside the MTCs [135, 236]. Direct transport of trauma patients to a MTC is proposed as one of the key elements that improve outcomes for injured patients [14]. However, this is difficult to implement in areas with scattered populations and potentially long transport distances. In such settings there is no evidence to support a direct transport to trauma center for all patients as the positive effect of the trauma center seems limited to those with major trauma and certain minor injuries [14, 103, 129, 155]. However, at what point the geographical factors and additional transport time outweighs the benefit for direct trauma center admission is yet to be determined. We observed (*study 2*) that ninety per cent of those admitted to ACH were not severely injured. Most of these patients were early discharged with good recovery and had minimal use of advanced medical interventions. Moreover, ACH delivered about forty per cent of the total number of hospital days showing that the use of ACH spared the MTC for a large number of admissions and a large number of hospital days. This result agree with Newgard et al. who reported that quality of care and cost-effectiveness did not increase for patients with minor injuries treated at a MTC [103]. Increased centralization transporting all trauma patients to a MTC may impact costs, total workload, hospital and transport resources negatively [103, 237]. Thus, the role of low-volume ACH might be more important for trauma care in mixed rural-urban areas than previously thought. However, there is also a cost associated with distributing trauma care to several centers. A continuous evaluation of cost and benefit is needed to ensure that patients receive the most appropriate level of care and that available resources are used judiciously.

While transport of patients with severe injuries to an ACH may cause delayed definite care, for some patients admissions to ACH may be necessary in order to provide initial stabilization before further transport [21, 237]. Forty-one per cent of major trauma patients were initially received at ACH, of which about half were later transferred to MTC. A substantial number of these initially showed signs of physiological derangement. Combined with long geographical distances, this would warrant initial treatment at a local ACH with adequate competence and resources. In these patients a trauma system should ensure that the ACH maintain competence and resources to resuscitate and stabilize before inter-hospital transfer for those in need of higher level of care and to provide definite care for those they are expected to. In addition adequate triage at the site of injury is needed in order to transport patients to the most appropriate hospital.

Prior to a continued centralization process, a detailed risk-analysis plan including the challenges posed by a scattered population and long geographical distances seems warranted. Implementing an inclusive trauma model in this setting would mean a continued effort in integrating all elements of care from adequate pre-hospital response, in-hospital treatment to rehabilitation.

7.2.3 Patient volume and quality of care

The actual threshold of volume of trauma patients needed to maintain sufficient quality in trauma care is still debated following several inconclusive reports [145, 150, 152]. The assumption is that increased patient volume of trauma patients in designated institutions increases quality of care and reduces mortality and morbidity, which is one of the cornerstones for the establishment of MTCs.

Compared with the national Norwegian annual number of injured patients (*n* = 540,000), our findings (*n* = 6.570) in *study 1,* suggested that only a minor number of patients are considered potentially severely injured [8]. The 2007 national Norwegian trauma report showed that 71 % (34/48) of hospitals received fewer than 100 trauma patients per year and that the majority of Norwegian hospitals treated few seriously injured patients [22]. In *study 1* we observed that by 2011 still 52.5 % (21/40) of the hospitals received fewer than 100 trauma patients, though this was a marked reduction from the previous report. Only five hospitals in 2011 (*study 1*) received more than 300 trauma patients per year. In 2005, Wisborg et al. found that in Scandinavia, the number of receiving hospitals ranged from 41 to 60 hospitals (except Iceland with two hospitals) within countries that had comparable populations and health system structures [238]. The high number of hospitals within each country leads to challenges with a low caseload of severe injuries for many hospitals. In *study 2* we observed that over a three-year period the total number of patients per hospital ranged from 39 to 993. Taking into account that the majority (80 – 94 %) (*Study 2*) of patients are not considered severely injured (ISS < 15); many hospitals still receive a small number of trauma patients and few gain substantial experience in treatment of these patients. In addition only one-hundred-and-twenty key emergency surgical procedures were performed on critically injured patients in eight hospitals over a three-year period (*Study 2*).

According to recommendations by ACS-COT a Level I trauma center should admit at least 1200 trauma patients annually, whereas 240 trauma patients should have an injury severity score (ISS) > 15 [21]. A volume of more than 35 major trauma patients per year per trauma surgeon has been suggested [153]. In the UK guidelines from 2009, it is suggested that major trauma centers (MTC) should admit at least 400 major trauma patients per year, though the exact definition of major trauma is not included. Each MTC should therefore provide service for a population size of approximately 2-3 million people. Observations from *study 1 and 2* clearly indicates in most hospitals a too low number of patients compared to trauma recommendations [21]. This questions the ability to gain and sustain adequate level of skill and competence in trauma care. To apply UK guidelines into a Norwegian context, would suggest the establishment of one to two MTCs serving the entire nation. With regards to a low population density and long geographical distances, such an approach would not be feasible. For that reason a carefully balanced adaption of acknowledged trauma recommendations weighted against national, regional and local needs as well as political, economic and medical aspects is needed [155]. Although a certain minimum in volume of trauma patients is needed to achieve sufficient experience, geography, residential pattern and structure of special national health services are also important factors for each country's or region's organization of trauma care [239]. Additional multi-professional training and education in surgical skills has shown to have to compensate some for a low trauma caseload [185, 240, 241].

7.2.4 Rurality and compensatory elements

Rural trauma is defined as *"trauma in which there is delayed or limited optimal care of the injured patient due to geography, weather, distance, or resources"* [21]. All these factors result in both a higher rate of deaths before and after arrival in hospital. In an international setting, large parts of Norway are likely to be referred to as a rural area or more correctly mixed urban-rural [177]. The ongoing centralization described in *study 1*, the low patient volume of severely injured described in *study 1 – 3* in a Norwegian setting of a mixed urban-rural environment adds to the challenges of providing equal access for all citizens, regardless of residential pattern [178]. This highlights that even though implementation of inclusive trauma systems have improved survival in some rural areas for those most severely injured [66] [160], efforts to improve coordination, training, education and establishment of transfer protocols is continuously needed [88].

A study by Kristiansen et al. that included 8466 trauma deaths in a 10-year period, observed a significantly higher mortality rate in rural areas compared to more urban areas. Additionally, they found that 78 % of trauma deaths occurred outside the hospital [9]. This implies that designing a trauma system for a country such as Norway with large rural areas, based on trauma models developed in highly urbanized areas, may be suboptimal. Adopting elements from well-documented trauma systems in regions with similar population and geographical characteristics may be advantageous for the Norwegian trauma system [18, 24, 140, 242].

Precise identification of the severely injured patient in the pre-hospital setting, available and competent EMS and HEMS, together with a dispersed hospital structure are key determinants in the Norwegian setting. Triage, occurring at several levels, is vital to the trauma system and determines the flow of patients [143, 243]. To dispatch the most appropriate resources, to choose the correct hospital and to decide whom to transfer from an ACH to the MTC, demands pre-defined criteria in order to be effective [21]. Only fourteen percent of all patients in *study 2* were major trauma, and a substantial clinical challenge exists in identifying these patients in a stressful and complex pre-hospital environment [103, 243]. A recent study revealed that field triage guidelines are "*relatively insensitive for identifying seriously injured* *patients and patients requiring early critical interventions*" [107]. Rehn et al. showed that increased competence by using trained anesthesiologists at the site of injury improved the ability to identify patients with severe injuries [219]. Physician manned HEMS are an integrated part of Norwegian pre-hospital services, and are expected to provide high-quality trauma triage and decision-making. The national air emergency services has a compensating effect to adjust for geographical dispersion and potential unequal access to advanced emergency medical care. However, the service is subjected to seasonal (e.g. weather conditions) and operational challenges which may reduce the all-year reliance of the service. This is something the trauma system needs to consider when allocating trauma resources.

Potentially severely injured patients should early be triaged to the closest available hospital, capable of managing their injuries. This should be based on common triage guidelines and well-educated pre-hospital personnel [21, 24, 82, 219].The hospitals should be accredited according to available trauma resources and should provide services according to predefined roles in trauma care.

7.2.5 Outcome

Mortality is an easily measurable and definite endpoint used for outcome measurements which allows for comparisons among countries and different trauma systems [186]. In *study 2* we observed a 30-day mortality of two per cent, and in *study 3* a 30-day mortality of one per cent. In *study 3* an additional 1.4 per cent died during the subsequent follow-up time. These numbers show that using mortality as a short- and long-term outcome measure in trauma may be a too crude measure. Mortality only captures a small proportion of the actual impact of trauma in a population. As most people experiencing trauma, survive, other long-term outcome variables after trauma seem more relevant. Though collecting outcome variables other than mortality may infer considerable challenges with regards to financial, logistical and legal barriers [28]. Multiple tools are in use, most of which are complex and expensive to apply, few of which have been validated in trauma care and are universally accepted [186] [198].

Functional outcomes measured over a longer period over time, are considered better to evaluate more aspects of the sequelae experienced after trauma. Though low-response rates in follow-up studies and questionnaires, cost, feasibility are all well-known limiting factors [200]. Longitudinal studies on health outcomes that extend beyond two years are few and mostly characterized by small cohorts and selected patient groups with specific injuries (i.e.

limb, spinal cord or head) [201, 205, 244-247]. Of the studies included in this thesis, *study 3* focused on the individual long-term effects of trauma. The initial primary outcome measures were "time to return to work" and "time to return to education". During the analysis phase the primary outcome of "receipt of medical benefits" was added, as we observed that this variable gave substantial added and important information to describe the course of patients following the sustained traumatic injuries.

Previous studies examining the association between magnitude of injury severity and reception of medical benefits at an individual level are sparse [248]. In a recent Scandinavian publication [248], linkages with national registries were used to assess the long-term effects of morbidity after trauma. There was a substantial increase in the rates of sick leave among injured patients compared with non-injured controls. Although this difference declined during follow-up (36 months), the non-injured controls had lower rates of sick leave many years after the incident [248]. This was explained by an increased prevalence of preinjury sick leave rates, substance abuse, and psychiatric and somatic co-morbidity in injured patients. A similar observation was made in *study 3*, with a persisting long-term effect of the injury on receipt of medical benefits, although this study population may be considered healthier as they were either in education or working at the time of the injury. There was a considerable post-trauma increase in the number of people receiving benefits, even among those with minor and moderate injuries, which persisted for some five years after the trauma. Patients with minor and moderate trauma represented 83.8 per cent of the injured patients in *study 3*. Therefore, even though the prevalence of receipt of medical benefits was lower after minor and moderate trauma, the total medical benefits received by those with minor or moderate injury might be equal to or greater than those received by patients with major injuries. The reason why these apparently healthy people with minor and moderate injuries needed long-term medical benefits was not explored. One possible explanation could be the sustained effects of the injury on physical and psychological health. Previous studies indicated that people who have experienced traumatic injuries have more conditions affecting mental health than the general population [249, 250]. In a cohort of severely injured patients, Gabbe et al. found that several factors unrelated to the injury itself (such as socioeconomic disadvantage and presence of pre-existing medical, drug, alcohol and mental health conditions) were associated with worse outcomes [251].

Other studies have found that a large number of those with severe injuries (ISS > 15) do not return to preinjury work activity within 12 months after trauma [191, 204]. In studies including patients with moderate and severe injuries (ISS > 9) [201, 205], about half of the patients returned to work. In *study 3*, 69.8 per cent of severely injured patients returned to preinjury level of work/education within the extended follow-up period. However, excluding the most severely injured, Fitzharris et al. noted a rate of return to work close to 90 per cent, but interestingly found that the majority returned to a different work role [252]. In a study of non-hospitalized injured patients, one-quarter returned to preinjury status, but subsequently deteriorated [253]. The results of these studies, together with the present findings, underline the importance of a long-term functional assessment and suggest that follow-up times should not be dependent on reaching a specific short-term target [253].

Using information about social security benefits as a measure of health and function has its limitations and must be done with caution. Previous studies have concluded that the duration of disability is not exclusively injury-dependent, but also depends on the characteristics of different compensation schemes [254, 255]. In *study 3*, the majority of the working population received medical benefits after trauma, with a steady decline towards the end of the first year. During this first year, the sickness benefits offered by the National Insurance Scheme (with universal benefits covering up to 100 per cent of previous income for all workers) are likely to reflect how injured people in the working population recover and regain their ability to work. This is not the case for non-working students who are not entitled to sickness benefits during the first few months after trauma.

Gradual establishment of a fixed level of patients receiving medical benefits was observed 12–15 months after injury in all severity groups. The timing of this turning point at exactly 12 months could reflect the characteristics of the Norwegian benefit system. After 52 weeks with sickness benefits, the level of compensation is reduced. The level of benefit receipt during the following years may be interpreted as a measure of disability, and was similar for workers and students. Goal-directed early rehabilitation during the first 12 months after injury may represent a window of opportunity for both facilitating faster recovery overall, but also to improve long-term functional level. For patients with minor and moderate injuries, early rehabilitation does not necessarily imply hospital admission, but frequent ambulatory assessments including healthcare counselling regarding strategies to treat pain, discomfort, problems with reduced mobility when undertaking daily activities, anxiety and depression, and thereby to reduce the effects of trauma [111]. This underlines the need to also include patients with minor trauma in order to understand the full impact of trauma on society [8, 230]. A reasonable question for policy decision-makers based on the present findings and those of other studies is whether intensified rehabilitation of those with minor or moderate trauma is as cost-effective as rehabilitation following major trauma.

7.3 Suggestions for future research

Traumatic injuries represent a major public health challenge on a global, national, regional and individual level. To ensure optimal trauma care, all components along the pathway of care needs to be evaluated. Key issues as described in the "*Utstein formula for survival*", is to use available high-quality scientific evidence, distribute knowledge by the means of efficient education and secure local implementation in the treatment chain to improve survival (and reduce morbidity) [256]. The development of trauma research has matured along with trauma system development, from case-series to cohort studies, and then further on to RCTs [19]. Even though RCTs provide the best methodological design to assess interventions, they may be difficult to perform in the acute care setting of trauma management. Issues such as randomly assignment to different levels of treatment, obtaining patient consent, identifying the fulfillment of inclusion criteria and securing standardization among several care takers and centers can reduce the quality of implementation [257]. The majority of evidence therefore currently relies primarily on observational studies and systematic reviews. Even if observational studies are prone to biases that make them less suitable for studying cause and effect, the combination of high quality health registries and well-designed epidemiological approaches could provide a future possibility to use *real-world data* to increase our clinical evidence base [258].

Using trauma registries and additional data capturing from contributing services is essential to generate knowledge about the care process. Providing high-quality data across the continuum of care has proven difficult, both due to medico-legal issues and the feasibility of data capturing in complex and hostile environments [90]. A scientific approach to provide a digital trauma data collection process across the continuum of care and applying an "*Episode of care model*" would allow for the use of risk-adjustment and outcome measures as tools to identify phase specific interventions [259]. Detailed knowledge of the effect of specific components in trauma care is important to enhance quality of care, but is currently lacking [260].

Implementation of trauma systems has reduced mortality and morbidity after trauma [12-14, 16]. These systems were described as establishing norms of care for all persons injured regardless of injury severity, though they still tend to focus mainly on those with potential severe trauma and/or those with life threatening injuries [21, 86]. For this reason the total burden of injury in a population often remains underestimated. In order to increase awareness in the society and identify areas for increased quality improvement, estimates of trauma should cover the whole spectrum of injury severity within a population [230].

As more patients survive their injuries, long-term functional outcomes become increasingly important and should be incorporated as part of clinical follow-up. As demonstrated in *study 3* the ability of linking clinical data with national registries should be further explored. Such a linkage has proven feasible and gives long-term functional outcome information with high validity and completeness.

8. Conclusions

Study 1

In 2011, hospital acute trauma care in Norway was delivered by four trauma centres and 37 acute care hospitals. Many hospitals still receive a small number of potentially severely injured patients and only a few hospitals have an electronic trauma registry. Future development of the Norwegian trauma system needs to address the challenge posed by a scattered population and long geographical distances. The implementation of a trauma system, carefully balanced between centres with adequate caseloads against time from injury to hospital care, is needed and has been shown to have a beneficial effect in countries with comparable challenges.

Study 2

In a region with a dispersed network of hospitals, geographical challenges, and low rate of major trauma cases, efforts should be made to identify patients with major trauma for treatment at a MTC as early as possible. This can be done by implementing triage and transfer guidelines, maintaining competence at ACHs for initial stabilization, and sustaining an organization for effective inter-facility transfers.

Study 3

Patients experiencing minor or major trauma received high levels of medical benefits; however, most recovered within the first year and resumed preinjury work activity. Patients with severe trauma were more likely to receive medical benefits and have a delayed return to work.

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10. Papers I-III

10.1 Copyright

10.2 Paper

Paper I

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Norwegian trauma care: a national cross-sectional survey of all hospitals involved in the management of major trauma patients.

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Paper I

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ORIGINAL RESEARCH Open Access

Norwegian trauma care: a national cross-sectional survey of all hospitals involved in the management of major trauma patients

Oddvar Uleberg[1,2*], Ole-Petter Vinjevoll[3], Thomas Kristiansen[4] and Pål Klepstad[2,5]

Abstract

Background: Approximately 10% of the Norwegian population is injured every year, with injuries ranging from minor injuries treated by general practitioners to major and complex injuries requiring specialist in-hospital care. There is a lack of knowledge concerning the caseload of potentially severely injured patients in Norwegian hospitals. Aim of the study was to describe the current status of the Norwegian trauma system by identifying the number and the distribution of contributing hospitals and the caseload of potentially severely injured trauma patients within these hospitals.

Methods: A cross-sectional survey with a structured questionnaire was sent in the summer of 2012 to all Norwegian hospitals that receive trauma patients. These were defined by number of trauma team activations in the included hospitals. A literature review was performed to assess over time the development of hospitals receiving trauma patients.

Results: Forty-one hospitals responded and were included in the study. In 2011, four trauma centres and 37 acute care hospitals received a total of 6,570 trauma patients. Trauma centres received 2,175 (33%) patients and other hospitals received 4,395 (67%) patients. There were significant regional differences between health care regions in the distribution of trauma patients between trauma centres and acute care hospitals. More than half (52.5%) of the hospitals received fewer than 100 patients annually. The national rate of hospital admission via trauma teams was 13 per 10,000 inhabitants. There was a 37% (from 65 to 41) reduction in the number of hospitals receiving trauma patients between 1988 and 2011.

Conclusions: In 2011, hospital acute trauma care in Norway was delivered by four trauma centres and 37 acute care hospitals. Many hospitals still receive a small number of potentially severely injured patients and only a few hospitals have an electronic trauma registry. Future development of the Norwegian trauma system needs to address the challenge posed by a scattered population and long geographical distances. The implementation of a trauma system, carefully balanced between centres with adequate caseloads against time from injury to hospital care, is needed and has been shown to have a beneficial effect in countries with comparable challenges.

Keywords: Epidemiology, Injury, Norway, Trauma, Trauma system

Background

The Global Burden of Injury Study reported a 9.3% reduction in deaths caused by injuries from 1990 until 2010; however, traumatic injury is still recognized as one of the primary challenges in modern health care [1,2]. Every year, approximately 5.1 million deaths worldwide are caused by injuries of any type, which represent a mortality rate of 74 per 100,000 persons and constitute the leading cause of death from 1 to 44 years of age [1,3]. The Norwegian mortality rate related to trauma varies among reports, with rates ranging from 29 to 77 per 100,000, depending on which definitions are used [4-10]. In Norway, approximately 540,000 persons are injured annually [8], 36,000 persons sustain permanent functional impairment, 1,200 persons receive disability pensions [8,11], and approximately 2,500 persons die as a result of accidents and violence, including self-inflicted injuries [8,11].

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Several publications have shown a beneficial effect with the implementation of trauma systems in terms of reduced morbidity and mortality [12-16]. Trauma systems advocate both preventative measures aimed at reducing the incidence of traumatic injuries, and pre- and in-hospital clinical efforts to reduce mortality and morbidity [12]. Several trauma models have been described, and the optimal organization of trauma care hospitals may be different in countries with a scattered population, such as Norway, compared with more populated areas [16,17].

In 2007, a national report on the current status of trauma services proposed the implementation of a national trauma system for Norway [18]. Hospitals receiving trauma patients should be organized into two levels and the regional health trusts decided as a policy that each health region should have one coordinating trauma centre. One university hospital in each region should act as the trauma centre and have the formal responsibility for regional trauma organization [7,18]. The other acute care hospitals should either provide initial stabilisation before transfer or definite trauma care [7,18]. Trauma centres should provide definite care for all injuries. Still, some hospitals, not defined as trauma centres, are equally able to provide trauma centre level of care [18-21].

The 2007 national trauma report showed that 71% (34/48) of hospitals received fewer than 100 trauma patients per year and that the majority of Norwegian hospitals treated few seriously injured patients [18]. Norwegian health care is in constant change. Therefore, the report published in 2007 may not represent the current number of hospitals involved in trauma care and the number of received patients per hospital. Thus, the aim of the study was to describe the current status of the Norwegian trauma system by identifying the number and the distribution of contributing hospitals and the caseload of potentially severely injured trauma patients within these hospitals.

Methods

Study setting

Norway has a scattered population and a low population density (15 inhabitants per km^2) [22]. The Norwegian mainland covers 324,000 km^2, with a straight-line distance of 1,800 km from north to south [22]. In 2011, Norway had a total population of 4,920,305 [23]. Previously, the responsibility of regional specialist health services, including hospital care, was provided by 19 counties. In 2002, this responsibility was assumed by five newly formed regional health authorities (RHA), which were reduced to four RHAs in 2007 [24]. As described in the national trauma report in 2007, 48 acute care hospitals nationwide received potentially severely injured patients, and the population covered by each hospital ranged from 13,000 to 2,500,000 [18].

All hospitals have predefined trauma teams, though the activation criteria show considerable variation among hospitals [22]. Criteria describing trauma transfers from acute care hospitals to trauma centres are generally lacking [25]. The pre-hospital emergency service is well established and consists of dispatch centres/emergency medical communication centres (EMCC), ground ambulances, on-call primary care doctors and air ambulances [22]. The helicopter service in the national air ambulance service consists of 12 primary air ambulance helicopters, which are manned with a pilot, an anaesthesiologist and a paramedic/rescuer [26]. Six search and rescue helicopters operated by the Royal Norwegian Air Force perform regularly ambulance missions and are also staffed with an anaesthesiologist as an integrated part of the national air ambulance services [26]. The health system is publicly funded and the Norwegian health legislation emphasises the importance of equal access for all citizens to adequate health care, regardless of residential pattern [24].

Study design

The study was conducted as a cross-sectional survey. The hospitals were identified through an overview of Norwegian hospitals provided by the National Directorate of Health and were included in the study if they A) had an emergency department, and B) had 24-hour acute surgical services [27]. In July 2012, a structured questionnaire was sent by electronic mail to each hospital's trauma coordinator. The questionnaire contained questions regarding the availability of a local electronic trauma registry and the number of trauma patients treated by trauma teams at their facility in 2011. A trauma patient/potential severely injured patient was defined as a patient receiving trauma team attendance, according to the hospital's trauma team activation (TTA) protocol [22]. Where applicable, number of patients who were transferred among hospitals was also included if this resulted in a TTA [22]. The hospitals that had no system for registration of potentially severely injured patients were asked to estimate the number of patients, based on other sources of information (e.g., manual counting of trauma charts and/or number of performed CT trauma protocols). If the hospital did not respond or if the answers were inconclusive, a follow-up telephone interview was conducted with the hospital trauma coordinator.

Information concerning time trends in hospital trauma care was obtained from an unstructured search of Norwegian scientific articles and white paper reports describing the Norwegian hospital acute care services.

Ethics

The Regional Committee for Medical and Health Research Ethics was informed about the study and decided that formal ethical approval was not required (REC Central Norway 2014/763).

Statistical analysis

Descriptive data are presented as absolute numbers, percentages and ranges, where appropriate. We used Pearson's chi-squared test to compare observations from different health regions. $P < 0.05$ was considered to be statistically significant. Data analysis was performed using statistical software (IBM Corp., released 2012. SPSS Statistics for Windows, Version 21.0.0.2, IBM Corporation, Armonk, NY, USA).

Results

Forty-one hospitals responded and were included in the study. A total of 6,570 trauma patients were admitted to four trauma centres and 37 acute care hospitals. Of these, 4,722 (72%) were exact figures based on the data in the trauma registries and 1,848 (28%) were estimated from other sources. Thirteen hospitals reported the existence of a local electronic trauma registry.

One third of the patients ($n = 2,175$; 33%) were admitted to a trauma centre, and two-thirds ($n = 4,395$; 67%) were admitted to acute care hospitals (Figure 1). The relative contribution from trauma centres in different regions ranged from 25% (Northern RHA) to 41% (Central RHA). Corresponding figures in Western RHA was 29% and 34% in South-East RHA, respectively. Comparing regions among each other, there were significant differences between three of four regions (p <0.05), except between Western and Northern RHA (p =0.10).

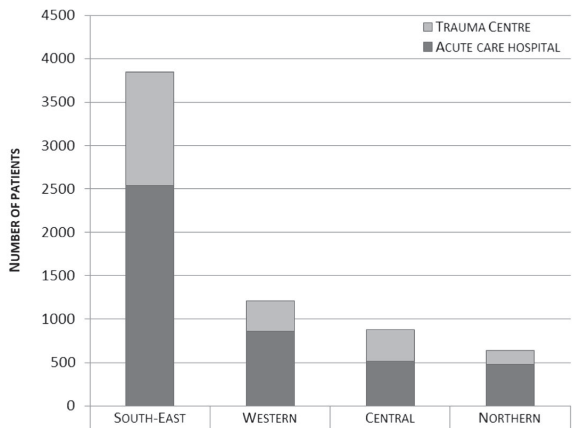
More than half of the hospitals (52.5%) received fewer than 100 trauma patients (Table 1).

The national rate of trauma admission was 13 per 10,000 inhabitants (Table 2). The total number of patients varied between health care regions (Figure 1); when adjusted for population, the admission rates per 10,000 inhabitants were similar in all regions (range 12–14) (Table 2). We found five articles and two white paper reports, in addition to our own findings ($n = 41$), regarding the number of hospitals receiving trauma patients [9,22,28-32]. There was a 37% (from 65 to 41) reduction in the number of hospitals involved in acute trauma care between 1988 and 2011 (Figures 2 and 3).

Discussion

Within the last two decades, there has been a substantial reduction in the number of Norwegian hospitals receiving potentially injured patients. Many hospitals still receive a small number of trauma patients, and only few hospitals have an electronic trauma registry. The number of trauma patients differs substantially among the four health regions, but the rates are similar when adjusted for population size. The acute care hospitals receive two thirds of all trauma patients and make a substantial contribution within the Norwegian trauma system. The distribution of patients between trauma centres and acute care hospitals shows regional variation.

In our study, we found an estimated 6,570 patients who were suspected of having a potential severe injury after accidents and who required specialist health care. Compared with the total national number of injured patients ($n = 540,000$), only a minor number of patients are



	South-East	Western	Central	Northern
Trauma Centre	1306	349	360	160
Acute care hospital	2539	863	516	477

Regional Health Authority

Figure 1 Distribution of patients per region and type of hospital.

Table 1 Distribution of patients within hospitals categorized by number of received patients

Categorization of hospitals by number of received patients	Number of hospitals (%)	Total number of received patients (%)
≤ 100	21 (52.5)	1,182 (18)
101 - 300	14 (35)	2,586 (39)
> 300	5 (12.5)	2,802 (43)
TOTAL	**40* (100)**	**6,570 (100)**

Two hospitals reported a collective number of patients.

considered potentially severely injured in the initial phase after injury [8]. The definition of severe injury/major trauma is internationally recognized as having an injury severity score (ISS) above 15 (ISS >15) [33,34]. In our study we chose to include patients receiving trauma team activation, in order to try to describe the overall workload of potential severely injured patients in Norwegian hospitals. TTA is performed when potential severe injury is anticipated [35]. To register ISS would have given more information about the patients' severities of injuries and the potential over-triage; however, this was not possible as many hospitals lack data on ISS [10,18]. Previous reports from Norwegian university hospitals have reported the rate of trauma patients having TTA with an ISS lower than 15 to be from 71% to 78%, corresponding to a high number of over-triage [21,36,37]. Applying these rates to our findings ($n = 6{,}570$), the total number of severely injured patients (ISS >15) is in the range of approximately 1,400 to 1,900 per year. These numbers are comparable to trauma care in Scotland (approximately 1,100 severe trauma cases per year/population of 5.2 million) and Finland (approximately 1,000-1,300 severe trauma cases per year/population of 5.3 million) [38,39]. A Norwegian study by Hansen et al. found the incidence of severe injury (ISS >15) in the western part of Norway to be 30 per 100,000 corresponding to 1,476 severely injured patients in Norway every year [4]. Notably, the study by Hansen et al. also included pre-hospital deaths [4].

Several studies and white paper reports have in the period from 1988 to 2011 described the number of hospitals receiving trauma patients (Figure 2) [9,22,28-32]. These and our findings show a 37% reduction in Norwegian hospitals receiving trauma patients (Figures 2 and 3) [9,22,28-32]. In 2005, Wisborg and colleagues found that in Scandinavia, the number of receiving hospitals ranged from 41 to 60 hospitals (except Iceland with two hospitals) within countries that had comparable populations and health system structures [40]. The high number of hospitals within each country leads to challenges with a low caseload of severe injuries for many hospitals. Fewer cases reduce the experience for each hospital's trauma teams and potentially result in poorer clinical outcomes [40]. In our study, we observed that although many hospitals still receive relatively few patients, the rate of hospitals receiving less than 100 patients is reduced from 71% (2007) to 53% (2011) [18]. The actual threshold in the volume of trauma patients needed to maintain sufficient quality in trauma care is debated [41]. North American recommendations for the needed volume of trauma patients range from 200 to 650 severely injured patients (ISS >15) or each surgeon should treat more than 35 patients with ISS >15 [42-44]. Although a certain minimum in volume of trauma patients is needed to achieve sufficient experience, geography, residential pattern and structure of special national health services are also important factors for each country's or region's organization of trauma care [38].

In our study we also found that there is an uneven admission rate between the regions in the number of patients transported directly to the trauma centres versus acute care hospitals (Figure 1). These differences may be caused by different organizational structure, geography and number of contributing hospitals. In the northern RHA a low initial admission rate (25%) to the regional trauma centre can be due to long distances, low population density and challenging weather conditions. Therefore, the initial admissions may often be at the closest local hospital. The relatively higher admission rate in the central RHA (41%) may be due to a smaller geographically defined area making transport directly to the trauma centre more feasible (Table 2). In the western RHA, potentially severely injured patients are admitted to two university hospitals with all surgical specialities, whereas only one is formally defined as a trauma centre. This resulted in a low trauma centre admission rate (29%) [19,20].

Table 2 Regional characteristics and trauma patients in different health regions per 10,000 inhabitants

	South-East RHA	Western RHA	Central RHA	Northern RHA	Norway
Population	2,743,875	1,028,069	680,110	468,251	4,920,305
Area (km^2)	111,012	43,439	56,385	112,946	323,782
Inhabitants per km^2	25	24	12	4	15
Number of patients	3,845	1,212	876	637	6,570
Number of hospitals	17	7	7	10	41
Patients per 10,000 inhabitants	14	12	13	14	13

RHA: Regional Health Authority.

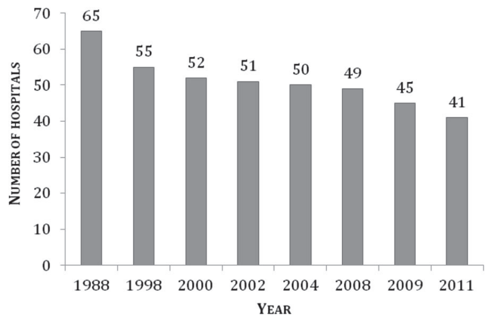


Figure 2 Number of Norwegian hospitals receiving trauma patients.

In a study by Kristiansen et al. that included 8,466 trauma deaths in a 10-year period, they observed a significantly higher mortality rate in rural areas compared to more urban areas. Additionally, they found that 78% of trauma deaths occurred outside the hospital [9]. This might imply that designing a trauma system for a country such as Norway with large rural areas, based on trauma models developed in highly urbanised areas, may be suboptimal. The establishment of a regionalised inclusive trauma system in Victoria, Australia showed significantly better functional outcomes and reduced mortality [16,45]. Adopting elements from well-documented trauma systems in regions with similar population and geographical characteristics may be advantageous for the Norwegian trauma system [10,16,45-47]. An inclusive trauma model contains all elements of trauma care from the pre-hospital phase, through hospital treatment both in trauma and non-trauma centres, and to end of rehabilitation. The exclusive systems focus primarily on trauma centres and their capabilities [17]. In a study by Utter et al. a 23% mortality reduction in an inclusive trauma system was observed compared to the more exclusive systems [17].

Challenges facing Norwegian trauma care are relatively many hospitals with a low caseload of severely injured patients, harsh climatic conditions and long geographic distances. A tendency towards centralisation has been observed, although there may be a lack of fully developed inclusive regional trauma systems [7]. Targeted resources must be allocated if Norway intends to maintain a geographically dispersed network of competent trauma hospitals. Implementing an inclusive trauma model in this setting would mean a continued effort in integrating all elements of care from adequate pre-hospital response, in-hospital treatment to rehabilitation. Potentially severely injured should early be triaged to the closest available hospital, capable of managing their injuries [10,19,21]. This should be based on common triage guidelines and well-educated pre-hospital personnel [10,19,21]. The hospitals should be accredited according to available trauma resources and should provide services according

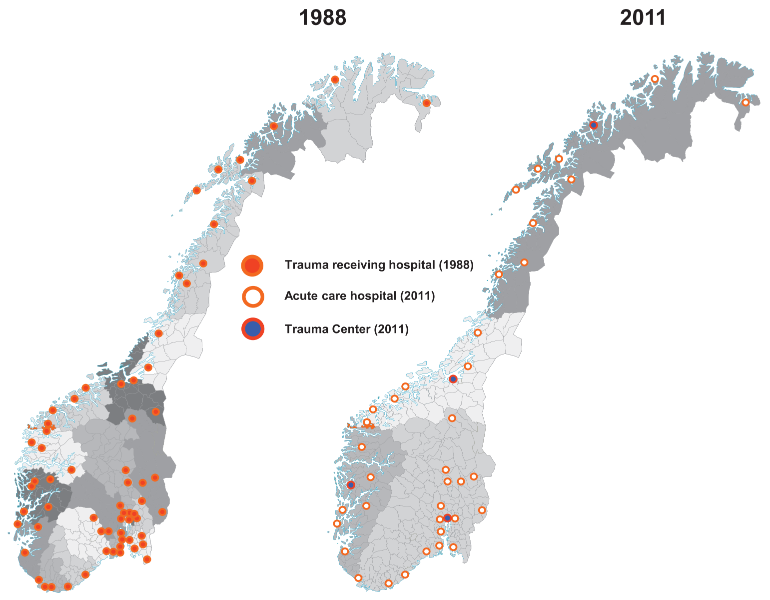


Figure 3 Overview of Norwegian hospitals receiving trauma patients in 1988 and 2011.

to predefined roles in trauma care. The national air emergency services has a compensating effect to adjust for geographical dispersion and potential unequal access to advanced emergency medical care. However, the service is subjected to seasonal (e.g. weather conditions) and operational challenges which may reduce the all-year reliance of the service. This is something the trauma system needs to be aware of when allocating trauma resources [28,48].

An implicit need in a well-designed mature trauma system is the availability of data on the incidence and distribution of injury, operational characteristics of the trauma system and functional outcome as provided by a quality registry [15]. In our study, we found that only 32% (13/41) of included hospitals had an electronic trauma registry. Previous investigations have found that there is no uniform reporting among these registries [10]. While some hospitals have used the trauma registry provided by the BEST initiative, some of the university hospitals have developed their own solutions [10,49]. The widespread lack of trauma care registrations in Norway is an obstacle against developing the optimal national trauma care system [8].

We recognise that this survey has several limitations. First, the present study collected data primarily by obtaining information from one contact person at each hospital. The responses were not validated, e.g., by interviewing other persons within the same hospital. Another limitation is that the number of trauma patients may be overestimated because some patients are initially received at local hospitals and are later transferred to trauma centres for definitive care [22]. Finally, the estimated the number of trauma patients in different hospitals may be influenced by different definitions used to identify trauma patients [22].

Conclusion

In 2011, acute hospital trauma care in Norway was delivered by four trauma centres and 37 acute care hospitals. This number of participating hospitals has been reduced by 37% since 1988. However, many hospitals still receive a small number of patients and only a few hospitals have an electronic trauma registry. Future development of the Norwegian trauma system needs to address the challenge posed by a scattered population and long geographical distances that influence timely access to definitive care. The implementation of a trauma system, carefully balanced between centres with adequate caseloads against time from injury to hospital care, is needed and has been shown to have a beneficial effect in countries with comparable challenges.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

O.P.V. and O.U. conceived and designed this study. O.P.V. collected the data and performed the telephone interviews. O.U. and T.K. prepared the figures and conducted the data analyses. O.U. drafted the manuscript. All authors interpreted the data and critically revised the manuscript. All authors have read and approved the final manuscript.

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Paper II

Uleberg O, Kristiansen T, Pape K, Romundstad PR, Klepstad P.

Trauma care in a combined rural and urban region: an observational study.

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Paper II

Trauma care in a combined rural and urban region: an observational study

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Conflict of interest
The authors declare no conflict of interest

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Background: The available information on trauma care in mixed rural-urban areas with scattered populations is limited. The aim of this study is to describe epidemiology, resource use, transfers and outcomes for trauma care within such an area, prior to implementation of a formal trauma system.

Methods: A multicentre observational study including potential severely injured patients from June 2007 to May 2010. All patients received by trauma teams at seven acute care hospitals (ACH) and one major trauma centre (MTC) were included. Major trauma was defined as Injury Severity Score (ISS) > 15.

Results: A total of 2323 patients were included. ACH received 1330 patients and delivered definite care to 85% of these. Only 329 (14%) patients were major trauma of which 134 (41%) were initially received at an ACH. Nine per cent of patients were transferred between hospitals. After inter-hospital transfers, 79% of all major trauma patients received definite care at the MTC. Helicopter emergency services admitted 52% of major trauma and performed 68% of inter-hospital transfers from ACH to MTC. Forty-eight patients (2%) died within 30 days.

Conclusion: In a region with a dispersed network of hospitals, geographical challenges, and low rate of major trauma cases, efforts should be made to identify patients with major trauma for treatment at a MTC as early as possible. This can be done by implementing triage and transfer guidelines, maintaining competence at ACHs for initial stabilization, and sustaining an organization for effective inter-facility transfers.

Editorial Comment

In this report, trauma care in a large mixed urban and rural health care system is analysed. In this system, there are large distances for transport involved, and relatively few major trauma events. The findings support the idea that it is an advantage to identify severely injured victims early, and have them transported as early as possible to definitive care at the major trauma centre.

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Most trauma care studies originate from major trauma centres (MTC) located in densely populated areas. Therefore the optimal organization of trauma care within regions with combined urban and rural populations and with a combination of MTC and low volume acute care hospitals (ACH) is not well-documented.[1–3]

In 2007 the four regional health trusts in Norway published recommendations for a national trauma care system.[4] This report, and similar publications from countries with comparable challenges (e.g. Canada, Scotland and Australia), states that there is limited information on both the incidence of traumatic injuries and the quality of trauma care in scattered populated areas.[4–7]

The primary aim of a trauma system is to treat patients at the right level of care. Therefore, an evaluation of trauma care must include detailed information on the epidemiology of trauma, patient demographics, use of interventions, clinical outcomes and patient transfers from the scene of the accident to definite care.[6,8,9] Still, most publications describing trauma system configurations usually focus on selected cohorts of the trauma population without containing enough detailed information to describe the entirety of a complete trauma system.[2,9–21]

To our knowledge, regional and population-based studies with involvement of all hospitals, including detailed pre- and in-hospital data for severity and acute interventions, and the extent of transfers between hospitals, is not previously published in a European setting. Thus, the aim of this study was to give a detailed description of epidemiology, resource use, transfers and outcomes for all potential severely injured patients admitted to hospitals within a defined geographical area with a combination of ACHs and one MTC prior to implementation of a formal trauma system.

Methods

Study design

This study is a retrospective analysis of prospective collected data from all hospitals within a defined geographical area. The study follows the 'Strengthening the reporting of observational studies in epidemiology' (STROBE) recommendations for reporting of observational cohort studies.[22]

Clinical setting

Central Norway is one of four regional health trusts in Norway, and covers an area of 56.385 km^2 with a total mixed urban/rural population of 677,308.[23, 24] In the study period, 1st of June 2007 to 31st of May 2010, eight hospitals admitted trauma patients (Fig. 1/ Table 1).[25] Following trauma system implementation (in 2014), local hospitals have been defined as ACH and the university hospital as a MTC. This corresponds to the hospitals actual role before the implementation of the trauma system, and, hence, we describe the hospitals in our study as ACH or MTC.

During the study period St. Olav's University Hospital served as the trauma referral centre (MTC) (Table 1). Injured patients in need of special surgical treatment (neuro-, paediatric- and cardiothoracic surgery) or multidisciplinary intensive care medicine were admitted directly to the MTC or transferred from an ACH. All hospitals had multidisciplinary trauma teams activated by predefined criteria and offered general surgical, orthopaedic and anaesthesia and intensive care medicine services, including x-ray and laboratory facilities (Table 1). Computer-tomography (CT) was accessible in all institutions.

Pre-hospital care was provided by approximately 90 paramedic manned ground-based emergency medical services (EMS), two paramedic and anaesthesiologist manned helicopter emergency medical services (HEMS) (Trondheim and Ålesund) and one military search and rescue (SAR) helicopter (Ørland). In addition two HEMS (Dombås and Brønnøysund) from other regional health care systems performed missions within the region. EMS as a rule brought the patients to the nearest hospital. HEMS could bypass the nearest hospital and bring the patients to the most appropriate facility following an on-scene evaluation. Based on the definition by the American College of Surgeons, we defined the local uptake area of the MTC as urban and the remaining areas as rural.[6]

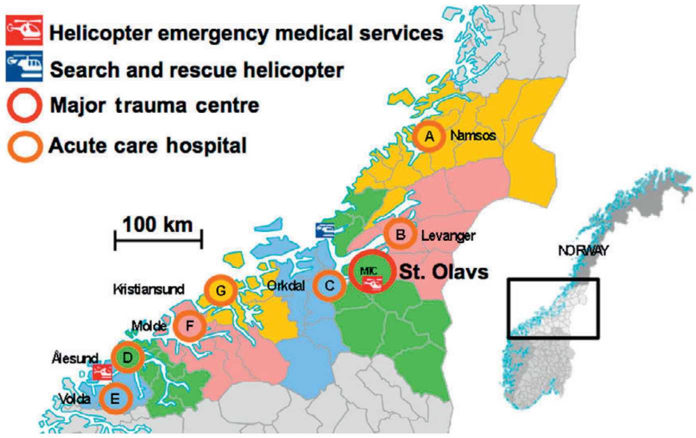

Fig. 1. Overview of hospitals and their local uptake area. The map gives a regional overview of all seven acute care hospitals (A to G) and the major trauma centre (MTC) in Trondheim. The coloured areas show each hospital's uptake area. [Colour figure can be viewed at wileyonlinelibrary.com]

Table 1 Structural characteristics of participating hospitals (n = 8).

	All hospitals	MTC	ACH A	ACH B	ACH C	ACH D	ACH E	ACH F	ACH G
Population (per 1st January 2009)[26]	677,308	238,640	40,959	91,787	48,092	97,996	42,322	70,177	47,335
Driving distance to MTC[27] minutes (km)	n.a	n.a	164 (195)	66 (81)	38 (41)	285 (290)	355 (347)	203 (219)	187 (196)
Air transport time to MTC* minutes	n.a	n.a	36	17	8	62	70	48	37
Defined trauma team	n.a	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Trauma team activation protocol	n.a	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Inter-hospital transfer criteria	n.a	n.a	No	No	No	No	No	No	No

MTC, Major Trauma Centre, ACH, Acute Care Hospital, n.a, not applicable, *air transport times was estimated using Garmin GNS430 given zero wind conditions and ground speed 120 knots. Air transport time gives the flight time only.

Patients and data collection

A trauma patient/potential severely injured patient was defined as a patient receiving trauma team attendance according to the hospital's trauma team activation (TTA) protocol.[26] All patients treated by trauma teams were included. Patients pronounced dead before hospital arrival were excluded. A major trauma patient was defined as a patient with Injury Severity Score (ISS) > 15. Clinical patient data were pre-defined according to the Utstein template for uniform reporting of data following major trauma.[27] Data were prospectively collected on a chart shared by all hospitals containing both pre-hospital and in-hospital information. Additional relevant information was obtained from the emergency medical coordination centre (EMCC) information system, EMS/HEMS reports and in-hospital electronic patient records. Data were recorded by a specially trained nurse at each study facility, using an encrypted web-based clinical registration form. This provided a collective set of de-identified clinical data from all institutions. The dataset was then manually searched to identify records from patients treated at two or more hospitals. Scores in patients with duplicate records were calculated based on data provided by the last treating hospital.

Seven specially trained nurses were formally educated according to the Association for the

Advancement of Automotive Medicine (AAAM) and coded the injuries using the Abbreviated Injury Scale (AIS) - Revision 2005.[28] Both the ISS and New Injury Severity Score (NISS) were calculated to allow comparison between studies.[27,29,30]

Physiological derangement was defined as pre-hospitals values of one or more of the following values: systolic blood pressure < 90 mmHg, respiratory rate (breaths per minute) < 10 or > 30 or Glasgow Coma Scale ≤ 8. The categories 'Head injury', ' Spinal injury', 'Thoracic injury', 'Abdominal/pelvic injury' and 'Extremity injury' included patients with an AIS ≥ 3 injury in the respective region. 'Polytrauma' was defined as AIS ≥ 3 in two or more body regions.[31] Paediatric patients were defined as 15 years or younger. When HEMS physicians accompanied ambulance transports, these were coded as EMS transports. The first key in-hospital emergency surgical interventions were defined as interventions within the first 24 h of admission.[27] Glasgow Outcome Score (GOS) was recorded at discharge according to the Utstein template.[27] This was done by the specially trained nurses performing the study registrations on the basis of the written clinical evaluations at discharge.

Ethics

The study was approved by the Regional Committee for Medical and Health Research Ethics (REC South East B, P.B. 1130 Blindern NO-0318 Oslo, reference 2010/2022b, dated 20th of September 2010).

Statistics

Descriptive characteristics of the study sample are presented as medians with inter-quartile ranges (IQR), and as absolute numbers, percentages and ranges. Student *T*-tests were used to compare mean values of continuous variables between two groups, whereas Pearson's chi-squared test was used for comparison of categorical variables. Statistical significance level was set at $P < 0.05$. Data analysis was performed using SPSS statistical software (IBM Corporation, released 2015. SPSS Statistics for Windows, Version 22, IBM Corporation, Armonk, NY, USA).

Results

A total of 2323 patients were included, of which 1550 (67%) were men. The median age was 35 years (range 0–92, IQR 19–50). Twelve per cent ($N = 283$) of the patients were paediatric. The number of patients directly admitted to the eight different hospitals varied between 39 and 993 (Table 2). Fifty-seven per cent ($N = 1330$) received initial treatment in an ACH (Table 2). Blunt trauma caused 97 per cent ($N = 2262$) of all injuries, and the majority of injuries were transport related ($N = 1607$ / 69%) or due to falls ($N = 450$ / 19%).

Injury severity

A total of 67% ($N = 1550$) of the patients in the study cohort had minor injury (ISS < 9) and 14% ($N = 329$) were major trauma patients (ISS > 15). Details of injuries are given in table 3. The incidence of major trauma patients was ~2 per 10,000 person-years. Characteristics of major trauma patients are shown in table 4. For major trauma patients 155 (47%) showed signs of physiological derangement (Table 4). The majority of major trauma patients received definite care at the MTC ($N = 259$ / 79%), of which 195 were admitted directly and 64 were transferred from an ACH. The major trauma patients who were admitted to an ACH and not transferred were older and had a lower ISS than those admitted directly or transferred to the MTC (Table 4).

Patient transfers

Nine per cent ($N = 203$) of patients were transferred between hospitals (Fig. 2). The majority of these ($N = 126$ / 62%) were transferred within 24 h. Eighty-one per cent ($N = 164$) of transfers were from an ACH to a MTC. The physician manned-HEMS performed 68% of the transports from an ACH to the MTC. Fifty-six major trauma patients initially brought to an ACH were admitted by HEMS. Thirty-one of these were later transferred to the MTC.

Table 2 Baseline characteristics of patients admitted directly to regional hospitals (n = 2323).

	All hospitals	MTC	ACH A	ACH B	ACH C	ACH D	ACH E	ACH F	ACH G
Patients directly admitted *n*	2323	993	165	174	39	493	111	267	81
TTA per 10,000 person-years	12	14	13	6	3	17	9	13	6
Injury Severity Score (ISS)									
Median (IQR)	4 (1–10)	5 (1–13)	4 (1–9)	4 (1–9)	4 (1–5)	5 (1–9)	4 (1–9)	4 (1–9)	2 (1–9)
Minor injury ISS 1–8 *n* (%)	1550 (67)	608 (61)	119 (72)	129 (74)	30 (77)	328 (67)	81 (73)	196 (73)	59 (73)
Moderate injury ISS 9–15 *n* (%)	445 (19)	190 (19)	34 (21)	33 (19)	7 (18)	107 (22)	23 (21)	36 (14)	14 (17)
Severe injury ISS > 15 *n* (%)	329 (14)	195 (20)	12 (7)	12 (7)	2 (5)	58 (11)	7 (6)	35 (13)	8 (10)
New Injury Severity Score (NISS)									
Median (IQR)	5 (1–12)	6 (1–17)	4 (1–11)	4 (1–9)	4 (1–12)	6 (2–12)	5 (2–10)	4 (1–10)	3 (1–9)
Minor injury NISS 1–8 *n* (%)	1409 (61)	553 (56)	110 (67)	116 (66)	29 (67)	289 (59)	76 (69)	179 (67)	57 (70)
Moderate injury NISS 9–15 *n* (%)	425 (18)	175 (18)	30 (18)	32 (18)	3 (8)	110 (22)	19 (17)	45 (17)	11 (14)
Severe injury NISS > 15 *n* (%)	489 (21)	265 (26)	25 (15)	26 (15)	7 (18)	94 (19)	16 (14)	43 (16)	13 (16)
Type of transportation to hospital									
EMS *n* (%)	1615 (70)	573 (58)	116 (70)	160 (92)	38 (97)	334 (68)	95 (86)	225 (84)	74 (91)
HEMS *n* (%)	670 (29)	398 (40)	49 (30)	13 (8)	1 (3)	154 (31)	15 (14)	40 (15)	0
Other *n* (%)	31 (1)	22 (2)	0	1 (< 1)	0	3^2 (1)	0	2 (1)	3 (4)
Unknown *n* (%)	5 (< 1)	0	0	0	0	0	1 (< 1)	0	4 (4)
Pre-hospital time*									
Median (IQR)	54 (34–86)	56 (32–97)	70 (37–97)	52 (34–77)	46 (23–80)	44 (30–64)	40 (40–88)	54 (34–75)	45 (25–65)
Length of stay									
< 3 days *n* (%)	1422 (61)	553 (56)	119 (72)	102 (58)	31 (79)	308 (63)	72 (65)	173 (65)	64 (79)
> 3 days *n* (%)	901 (39)	439 (44)	46 (28)	73 (42)	8 (21)	185 (37)	39 (35)	94 (35)	17 (21)

MTC, Major Trauma Centre, ACH, Acute Care Hospital, TTA, Trauma Team Activation IQR, interquartile range, EMS: Emergency Medical Services, HEMS: Helicopter EMS, *125 missing values.

Resource use

The patients total hospital length of stay (LOS) was 7228 days at the MTC and 5122 days at the ACHs. Sixty-one per cent of the patients had a hospital LOS less than 3 days. Two-hundred-and-sixty-five patients had a total ventilator time of 2041 days (MTC 1713 days / ACH 327 days) (Table 3). The major trauma patients used 39% of the total hospital days (4851 days) and 88% of ventilator time (1787 days) (Table 4). Hundred-and-twenty key emergency surgical procedures were performed within the first 24 h of arrival to the hospital (Table 3). Of these procedures 89% (N = 107) were performed at the MTC. Five patients underwent key emergency surgical interventions prior to transfer to MTC. The physician manned-HEMS transported 670 (29%) of the patients from site of injury of which 172 (26%) were major trauma patients, higher than the rate of 9% major trauma patients transported by paramedic manned EMS (P < 0.001) (Table 2).

Outcome

At hospital discharge 1849 patients (79%) had a good neurological outcome (GOS 5), 190 moderate disability (GOS 4), 48 severe disability (GOS 3) and 5 were vegetative (GOS 2). Forty-eight

Table 3 Characteristics among directly admitted and transferred patients (*n* = 2323).

	MTC (directly admitted)	ACH (directly admitted/not transferred)	Transferred to MTC (include external MTCs)	Transferred to ACH/External
Total *n*	993	1127	164*	39
Age median (IQR)	34 (19–49)	36 (19–51)	37 (20–51)	30 (18 - 56)
Male *n* (%)	672 (68)	731 (65)	123 (75)	24 (62)
Injury Severity Score (ISS) > 15	195 (20)	60 (5)	64 (39)	10 (26)
New Injury Severity Score (NISS) > 15	265 (27)	117 (10)	94 (57)	14 (36)
Mechanism of injury *n* (%)				
Traffic; motor vehicle injury	448 (45)	618 (55)	68 (41)	19 (49)
Traffic; motorcycle injury	102 (10)	77 (7)	21 (13)	4 (10)
Traffic; cyclist/pedestrian	115 (12)	91 (8)	8 (5)	5 (13)
Traffic; other	21 (2)	7 (1)	2 (1)	0
Fall	196 (20)	210 (19)	39 (24)	5 (13)
Violence; blunt/penetrating	58 (6)	74 (6)	8 (5)	2 (5)
Other	53 (5)	50 (4)	18 (11)	4 (10)
Head injury *n* (%)	58 (6)	39 (3)	22 (13)	3 (8)
Spinal injury *n* (%)	23 (2)	9 (< 1)	18 (11)	0
Thoracic injury *n* (%)	86 (9)	66 (6)	14 (9)	3 (8)
Abdominal/pelvic injury *n* (%)	14 (1)	12 (1)	9 (6)	0
Extremity injury *n* (%)	35 (4)	38 (3)	15 (9)	7 (18)
Other *n* (%)	12 (1)	7 (< 1)	4 (2)	1 (3)
Polytrauma *n* (%)	100 (10)	26 (2)	34 (21)	8 (44)
Intubated – prior to hospital arrival *n* (%)	79 (8)	13 (1)	35† (21)	0
Thoracic drainage – prior to hospital arrival *n* (%)	11 (1)	4 (< 1)	10 (6)	0
Helicopter emergency services (HEMS) *n* (%)	398 (40)	205 (18)	112‡ (68)	13 (33)
ICU admission *n* (%)	672 (68)	732 (65)	152 (93)	33 (85)
Number of patients on ventilator *n* (%)	161 (16)	43 (4)	55 (34)	6 (15)
Days on ventilator *median (IQR)*	3 (1–10)	1 (1–3)	1 (1–2)	1 (1–5)
First key emergency intervention total *n*	86	8	23§	3
Damage control thoracotomy	3	0	0	0
Damage control laparotomy	22	7	4	1
Extra peritoneal pelvic packing	1	0	1	0
Limb revascularization	1	0	0	0
Interventional radiology	5	0	0	2
Craniotomy	7	0	5	0
Intracranial pressure device insertion	47	1	13	0
Glasgow Outcome Scale (GOS) at discharge *n* (%)				
5 = Good recovery	833 (84)	934 (83)	64 (39)	18 (46)
4 = Moderate disability	98 (10)	44 (4)	43 (26)	5 (13)
3 = Severe disability	30 (3)	4 (< 1)	14 (9)	0
2 = Persistent vegetative state	5 (< 1)	0	0	0
1 = death	26 (3)	13 (1)	2 (1)	0
0 = Unknown	1	132 (12)	41 (25)	16 (41)
Mortality 30 days after injury *n* (%)	27 (3)	16 (1)	5 (3)	0

MTC, Major Trauma Centre, ACH, Acute Care Hospital, External, hospitals outside the health region, IQR, interquartile range, *17 patients were transferred to external MTCs, †number of patients intubated prior to arrival at MTC, ‡number of patients transported by HEMS to MTC, §include interventions performed at MTC.

(2%) of admitted patients died during the first 30 days after trauma; 27 patients were primarily admitted to the MTC while 21 patients were admitted to ACH.

The patients who died were mostly male (*N* = 34 / 70%) and median age was 60 years (range 1–91, IQR 38–78). Median ISS was 29 (range 1–75); however, 12 of the patients who

Table 4 Characteristics of major trauma patients with Injury Severity Score > 15 (*n* = 329).

	All hospitals	MTC (directly)	ACH (directly admitted/ not transferred)	Transferred to MTC (include external MTCs)	Transferred between ACHs
Total *n*	329	195	60	64†	10
Age median (IQR)	39 (21–56)	34 (20–52)	54 (33–70)	35 (20–52)	51 (18–71)
ISS median (IQR)	22 (18–29)	25 (19–33)	20 (17–24)	22 (17–28)	20 (17–24)
NISS median (IQR)	27 (22–38)	29 (22–41)	25 (21–30)	27 (22–34)	20 (17–19)
Length of stay days	4851	2835	979	943	94
Ventilator time days	1787	1192	124	445‡	26
Patients with physiological derangement *n* (%)	155 (47)	103 (53)	19 (32)	30 (50)	3 (30)
Systolic blood pressure* median (IQR)	120 (110–140)	144 (109–140)	125 (118–148)	130 (113–144)	150 (130–160)
Systolic blood pressure < 90 mmHg* *n* (%)	44 (13)	30 (16)	8 (13)	6 (9)	0
Glasgow Coma Scale* median (IQR)	14 (8–15)	13 (7–15)	15 (13–15)	15 (11–15)	15 (15)
Glasgow Coma Scale ≤ 8* *n* (%)	87 (26)	61 (31)	9 (15)	15 (23)	2 (20)
Respiratory rate per min > 30 or < 10* *n* (%)	98 (30)	54 (28)	19 (32)	22 (34)	3 (30)
Mortality 30 days after injury *n* (%)	36 (11)	23 (12)	9 (15)	4 (6)	0

MTC, Major Trauma Centre, ACH, Acute Care Hospital, IQR, interquartile range, ISS, Injury Severity Score, NISS, New Injury Severity Score, *pre-hospital physiological observations, †five patients were transferred to external MTC, ‡317 ventilator days were in MTC.

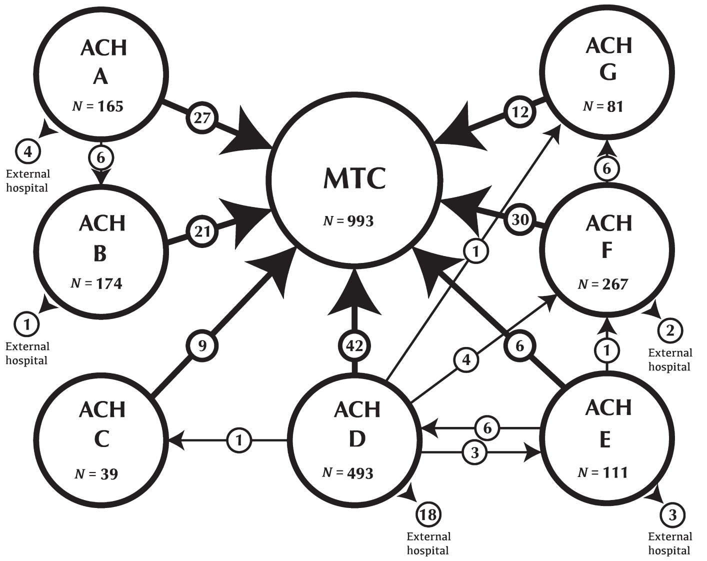

Fig. 2. Overview of patient flow among hospitals. The flow chart shows transfers between acute care hospital (ACH) and the major trauma centre (MTC). The number inside the circles gives the number of direct hospital admissions. External hospitals are hospitals outside the region.

died had an ISS less than 15. These patients had a median age of 72 years (range 9–89, IQR 61–86). The ACH patients (not transferred) who died were older (median age 78 / IQR 66–87) and less severely injured (median ISS 16 / IQR 9–30) than both those directly admitted to the MTC (median age 50 / IQR 26–66 - median ISS 29 / IQR 25–45) and those transferred to the MTC (median age 51 / IQR 37–67 - median ISS 25 / IQR 14–31).

Discussion

We observed that in a mixed urban-rural health care region the total number of major trauma patients was low, and the majority of major trauma patients received definite care at the MTC. Still, 41% of major trauma patients were initially received at an ACH, often because transport distance to MTC and physiological instability made a direct MTC admission challenging. In general, patients were primarily transported from the site of injury to hospital by road ambulances, while HEMS admitted more than half of all major traumas patients. ACH received more than half of all patients for which they delivered definite care to eighty-five per cent. Patients not transferred from ACH to MTC were older and less severely injured than those transferred.

Several studies have reported that a large number of patients are initially managed outside the MTC.[2, 11] Direct transport of trauma patients to a MTC is proposed as one of the key elements that improve outcomes for injured patients.[3] However, this is difficult to implement in areas with scattered populations and potentially long transport distances. Further, in such settings there is no evidence to support a direct transport to trauma centre for all patients as the positive effect of the trauma centre seems limited to those with major trauma and certain minor injuries.[3,32–34] However, at what point the geographical factors and additional transport time outweighs the benefit for direct trauma centre admission is yet to be determined. We observed that ninety per cent of those admitted to ACH were not severely injured. Most of these patients were early discharged with good recovery and had minimal use of advanced medical interventions. Moreover, ACH delivered about forty per cent of the total number of hospital days showing that the use of ACH spared the MTC for a large number of admissions and a large number of hospital days. This result agree with Newgard et al. who reported that quality of care and cost-effectiveness did not increase for patients with minor injuries treated at a MTC.[32] Increased centralization transporting all trauma patients to a MTC may impact costs, total workload, hospital and transport resources negatively.[32,35] Thus, the role of low-volume ACH might be more important for trauma care in mixed rural-urban areas than previously thought. However, there is also cost associated with distributing trauma care to several centres. A continuous evaluation of cost and benefit is needed to ensure that patients receive the most appropriate level of care and that available resources are used judiciously.

While transport of patients with severe injuries to an ACH may cause delayed definite care, for some patients admissions to ACH may be necessary in order to provide initial stabilization before further transport.[6, 35] Forty-one per cent of major trauma patients were initially received at ACH, of which about half were later transferred to MTC. Whether this was an expression of inadequate triage, logistic challenges or immediate need for lifesaving interventions could not be sufficiently described in our study. A substantial number of these initially showed signs of physiological derangement. Combined with long geographical distances, this would warrant initial treatment at a local ACH with adequate competence and resources. In these patients a trauma system should ensure that the ACH maintain competence and resources to resuscitate and stabilize before inter-hospital transfer for those in need of higher level of care and to provide definite care for those they are expected to. In addition adequate triage at the site of injury is needed in order to transport patients to the most appropriate hospital.

Triage, occurring at several levels, is a vital to the trauma system and determines the flow of patients.[19,36] To dispatch the most appropriate resources, to choose the correct hospital and to decide whom to transfer from an ACH to the MTC, demands pre-defined criteria in order to be effective.[6] Only fourteen percentage of all patients were major trauma, and a substantial clinical challenge exists in identifying these patients in a stressful and complex pre-hospital environment.[19,32] A recent study revealed that field triage guidelines are 'relatively insensitive for identifying seriously injured patients and patients requiring early critical interventions'.[37] Rehn et al. showed that increased competence by using trained anaesthesiologists at the site of injury improved the ability to identify patients with severe injuries.[38] Physician manned HEMS are an integrated part of Norwegian pre-hospital services, and are expected to provide high-quality trauma triage and decision-making. In this study, only thirty per cent of patients were transported by HEMS from the site of injury and fifty-two per cent of major traumas were initially transported from the site by HEMS. Reasons for possible under-utilization is uncertain, but might be indicative of poor dispatch criteria, long travel distances from the helicopter bases to scene, or accidents occurring in urbanized areas close to the hospitals. The frequent use of road ambulance service despite the organisation of a dedicated HEMS service also illustrate that the activities from one emergency service do not exclude the need for other services; on the contrary different pre-hospital services must complement each other and all parts involved in emergency medicine must have basic training in trauma care.

We recognize some limitations in our study. First, due to inclusion criteria, those with major trauma and not treated by trauma teams (i.e. undertriage), were not included as there were no incorporated system to capture these patients. Previous reports have described rates of undertriage from 10 to 19 per cent.[38–40] Second, because national identity numbers were not available, non-Norwegian patients was not followed after discharge for 30 day mortality. However, this bias is limited both to a low number of foreign patients and due to that patients discharged is expected to live for 30 days. Third, as there was no regional system or registry to ensure data capture on pre-hospital deaths, the study did not include those patients who died before hospital arrival. Previous publications have described the rate of pre-hospital deaths ranging 69% to 78% of all trauma deaths.[21,41] Fourth, the study was not designed to compare outcomes between ACH and MTC admissions. Such a comparison would be affected by several selection biases (e.g. weather, distance to hospital, triage decisions at scene of accident) and would need another study design. Finally, we do not know the number of patients with major trauma transported to the MTC as the closest hospital or after a triage decision.

In a region with a dispersed network of hospitals, geographical challenges, and low rate of major trauma cases, efforts should be made to identify patients with major trauma for treatment at a MTC as early as possible. This can be done by implementing triage and transfer guidelines, maintaining competence at ACHs for initial stabilization, and sustaining an organization for effective inter-facility transfers.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Table S1. Overview and quality of all study variables (n = 41)

Paper III

Uleberg O, Pape K, Kristiansen T, Romundstad PR, Klepstad P.

Population-based analysis of the impact of trauma on longer-term functional outcomes.

Br J Surg. 2019 Jan; 106(1): 65-73. doi: 10.1002/bjs.10965.

Paper III

Original article

Population-based analysis of the impact of trauma on longer-term functional outcomes

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Background: **Functional outcome measures are important as most patients survive trauma. The aim of this study was to describe the long-term impact of trauma within a healthcare region from a social perspective.**

Methods: **People active in work or education and admitted to hospitals in Central Norway in the interval 1 June 2007 to 31 May 2010 after sustaining trauma were included in the study. Clinical data were linked to Norwegian national registers of cause of death, sickness and disability benefits, employment and education. Primary outcome measures were receipt of medical benefits and time to return to preinjury work level. Secondary outcome measures were mortality within 30 days or during follow-up.**

Results: **Some 1191 patients were included in the study, of whom 193 (16·2 per cent) were severely injured (Injury Severity Score greater than 15). Five years after injury, the prevalence of medical benefits was 15·6 per cent among workers with minor injuries, 22·3 per cent in those with moderate injuries and 40·5 per cent among workers with severe injuries. The median time after injury until return to work was 1, 4 and 11 months for patients with minor, moderate and severe injuries respectively. Twelve patients died within 30 days and an additional 17 (1·4 per cent) during follow-up.**

Conclusion: **Patients experiencing minor or major trauma received high levels of medical benefits; however, most recovered within the first year and resumed preinjury work activity. Patients with severe trauma were more likely to receive medical benefits and have a delayed return to work. Registration number: NCT02602405 (http://www.clinicaltrials.gov).**

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Introduction

Despite improvements in injury prevention and systematic trauma care, traumatic injuries impart a significant healthcare burden. There are 4·8 million deaths annually and 973 million people seeking healthcare globally[1]. The impact of trauma is usually measured in terms of risk-adjusted mortality rates and short-term outcome measures[2]. However, survivors of trauma frequently have long-lasting effects including physical and/or psychosocial harm and problems undertaking daily activities[3–5].

Employment is recognized as an important determinant of health status[6]. Return to work or education is therefore recommended as a measure of long-term functional level, indicating the ability to combine both physical and mental skills in performing complex and compound tasks[2,6]. Not participating in work or education is associated with both economic consequences and psychological distress[6,7]. Several studies have been published on return to work after trauma; however, the overall public health perspective tended to be restricted owing to small sample sizes[8–12], or focus on selected groups of patients with specific injuries[13–16] or specific mechanisms of injury[17,18]. Two large population-based studies[19,20] from the Victorian State Trauma Registry in Australia reported long-term follow-up data regarding return to work, but included only the most severely injured patients. To describe the overall consequences of trauma for a population, studies should ideally include all injured patients within a geographical area, within a specified time interval and with complete data capture for follow-up.

The aim of this study was to describe the long-term consequences of trauma in a cohort that included all patients with traumatic injury in a healthcare region, using return to work and receipt of medical benefits as primary outcome measures, and mortality as a secondary outcome.

Methods

A population-based cohort study was undertaken that followed injured patients over time using data supplied by national economic and social benefit registers. It was registered at ClinicalTrials.gov (NCT02602405) and conformed to the STROBE recommendations for reporting of observational studies[21]. The study protocol was approved and the need for patient consent was waived by an independent ethics committee (Regional Committee for Medical and Health Research Ethics South-East; reference number REC 2015/1582).

Study setting and population

Central Norway is one of four regional health Trusts in Norway. It covers an area of 56 385 km^2 and has a total population of 680 110 inhabitants[22]. The study population included all patients aged 16 to 65 years who experienced traumatic injury, and who were in work-related activity at the time of injury and admitted to one of the seven publicly funded hospitals (1 major trauma centre and 6 acute-care hospitals) in the interval from 1 June 2007 to 31 May 2010. No private hospitals in the region received injured patients. Patients pronounced dead before arrival at hospital and those without a unique 11-digit Norwegian national identity number were excluded. Twenty-seven patients with several trauma admissions were each analysed with respect to the first incident. Work-related activity at the time of injury was defined as work or educational activity in at least 1 of the 2 months before the injury. This included those who were registered students, and/or had a registered employer, and/or had an annual income of more than €10 581 (100 000 Norwegian kroner; exchange rate 16 July 2018). Patients who received medical or sickness benefits in the 2 months before injury were excluded.

Injured patients were defined as those who potentially had severe injuries and were received by a multidisciplinary trauma team. Trauma teams were activated according to recommended criteria indicating physiological derangement, anatomical injuries and mechanisms of injury likely to cause severe injury[23]. However, the specific criteria varied among individual hospitals[24]. These teams consist of different medical specialties capable of providing immediate care for life-threatening injuries on arrival in the emergency department.

Study variables

Clinical data were predefined using the Utstein template for uniform reporting of data following major trauma[25]. Data were collected on hospital admission (*Table S1*, supporting information) and extracted retrospectively for the purposes of this study. For patients who were treated at two or more hospitals, the injury scores were calculated based on data from the last treating hospital. Injury Severity Score (ISS) was used to define injury severity using the Abbreviated Injury Scale (AIS) – revision 2005 of the Association for the Advancement of Automotive Medicine[26]. ISS is calculated as the sum of the square of the AIS score for the three most severe injuries in different ISS body regions. The AIS is a six-point ordinal scale classifying the severity of each anatomical injury (head, spine, upper and lower extremities, face/neck, thorax, abdomen and external) from 1 (minor) to 6 (maximum). The ISS ranges from 0 to 75, where a score exceeding 15 is considered a major trauma with a predicted risk of death higher than 10 per cent[27,28]. Injury severity was classified into three groups: minor trauma (ISS below 9), moderate trauma (ISS 9–15) and severe trauma (ISS over 15). Severe head trauma was defined as an AIS-Head score of 3 or more. Key emergency surgery procedures comprised major immediate life-saving surgical interventions defined according to the Utstein template[25].

Linkage and follow-up

Patients were linked to individual data from national registers throughout 2014, using the unique 11-digit personal identity number given to all Norwegian citizens. Statistics Norway provided data on education from the national education database, as well as data on income and demographics. The Norwegian Cause of Death Registry, administered by the Norwegian Institute of Public Health, provided data on time and causes of death. Information on medical benefits and employment was obtained from the national event (FD-Trygd) database, provided by Statistics Norway[29]. These data contain complete details of type of medical benefits, and entry and exit dates for the different benefits.

All Norwegian citizens are compulsory members of the National Insurance Scheme, which offers universal sickness and disability benefits to compensate for loss of income and inability to work caused by health impairment. Employed people can be granted sickness benefits (covering up to 100 per cent of income) for a period of 52 weeks. After this, patients can receive long-term medical benefits or disability pension, usually covering up to 66 per cent of former income. Occupational disability both before and after 52 weeks needs to be documented by a doctor's certificate.

These long-term benefits may also be granted to students and young people without work experience. Disability pension requires a reduction in work ability of at least 50 per cent owing to permanent disease, injury or impairment. In this study, medical benefits were defined as any form of sickness benefit or disability pension.

Outcome variables

Primary outcome measures were receipt of medical benefits and time to return to preinjury work level. These were constructed by combining information on employment status, receipt of medical benefits, educational status and income from each calendar month during follow-up and also for the 2 years preceding the injury. Secondary outcome measures were mortality within 30 days and mortality during the follow-up period.

Medical benefit receipt included all sickness and disability benefits. Return to preinjury work level was defined as return to the same or a higher level of activity compared with 2 months before injury (preinjury work level). Work activity level was assessed in three groups: full-time workers worked 30 h per week or earned more than €31 746 per year; part-time (large) workers undertook 20–30 h per week or earned €21 164–31 746 per year; and part-time (little) workers undertook 0–20 h per week or earned €10 581–21 163 per year (all converted from Norwegian kroner; exchange rate 16 July 2017). The term workers included people in full- or part-time employment. Students could not be included in the analyses of return to work activity because the educational data did not provide the necessary details to identify monthly changes in status.

Co-variables

The models included age, sex and educational level as these were considered potential confounding factors. Baseline educational level was assessed at the time of trauma and categorized in three levels: primary (primary and lower secondary school education), secondary (upper secondary school and postsecondary non-tertiary education) and tertiary (undergraduate, graduate and postgraduate education). Dates of emigration and old age retirement (over 67 years) were also collected from the registry data.

Statistical analysis

Associations between trauma severity (3 ISS groups) and presence of severe head injury (AIS-Head score at least 3) with the study outcomes (receipt of medical benefits, return to preinjury activity level and death) were assessed in separate analyses. All patients were followed with monthly registration of receipt of medical benefits (yes/no) from 2 years before up to 6 years (72 months) after trauma, censoring observations in the event of death, emigration, old age retirement or 31 December 2014 (last available date for registry data). The 2-year interval before injury was included to provide a baseline for comparison for each group. Information from these monthly registrations was used to assemble dichotomous data on benefit receipt during 3-month intervals; in total there were eight periods before and 24 after injury. Longitudinal logistic regression models were generated (general estimating equations) to explore the association between injury characteristics and benefit receipt, including time periods (32 3-month intervals) as a categorical variable in the models. An interaction term between the time variable and trauma severity was included to allow for different trajectories of benefit receipt over time for patients with different injury severity. All analyses were adjusted for sex, age and educational level. Estimates from population-averaged regression analyses were used to calculate predicted level of benefit receipt with 95 per cent confidence intervals, according to time and injury severity (for graphical representations). The analyses were repeated for subgroups according to preinjury activity (workers and students).

For analyses of time to return to work, patients were followed from the first month after injury to the first month with return to preinjury work activity level, disability pension, death, emigration, old age retirement or January 2015 (whichever came first), within a time frame of 72 months

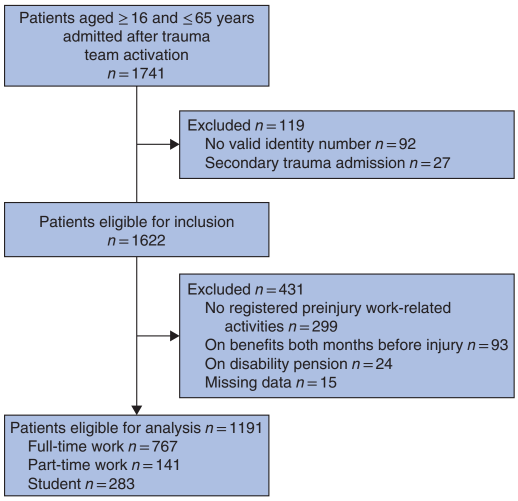


Fig. 1 Study flow chart

Table 1 Baseline characteristics of eligible patients

	No. of patients* (*n* = 1191)
Age (years)†	27 (19–45)
Sex ratio (M : F)	828 : 363
Level of education	
Primary	513 (43·1)
Secondary	488 (41·0)
Tertiary	190 (16·0)
Injury Severity Score†	4 (1–10)
< 9 (minor injury)	772 (64·8)
9–15 (moderate injury)	226 (19·0)
> 15 (severe injury)	193 (16·2)
Severe regional injury‡	
Head	109 (9·2)
Face	14 (1·2)
Neck	2 (0·2)
Thoracic	168 (14·1)
Abdominal	33 (2·8)
Spinal	60 (5·0)
Extremity	95 (8·0)
Other/external	3 (0·3)
ICU/HDU admission	820 (68·8)
On ventilator	135 (11·3)
Key emergency surgery procedure§	68 (5·7)
Duration of stay in hospital (days)†	2 (1–5)
0–3	713 (59·9)
> 3	478 (40·1)
Death	
Within 30 days of injury	12 (1·0)
During entire follow-up	29 (2·4)

*With percentages in parentheses unless indicated otherwise; †values are median (i.q.r.). ‡Defined by an Abbreviated Injury Scale score of at least 3. §According to the Utstein template for uniform reporting of trauma[25]. HDU, high-dependency unit.

after injury. Only patients actually in work before injury were included in this analysis. For mortality analyses, all patients were followed from the day after trauma to the date of death, emigration or 31 December 2014, whichever came first. Kaplan–Meier survival analyses were performed to estimate time to event (return to work or death) for patient groups according to injury severity. For multivariable analyses, Cox proportional hazards regression models (adjusting for sex, age and educational level) were used to compare groups according to injury severity; hazard ratios (HRs) with 95 per cent confidence intervals were estimated.

No prestudy sample size estimation was undertaken as there was limited information on specified outcome measures and the intention of the study was not to compare any interventions. Stata® version 14 (StataCorp, College Station, Texas, USA) was used for all statistical analyses.

Results

A total of 1191 patients with traumatic injuries were included in the study (*Fig. 1*), of whom 828 were male (69·5 per cent). Median age was 27 (i.q.r. 19–45) years. Some 193 patients (16·2 per cent) were severely injured (ISS over 15) and 109 (9·2 per cent) had a severe head injury (AIS-Head at least 3) (*Table 1*). Among the severely injured, 85 patients (44·0 per cent) had a severe head injury.

Receipt of medical benefits

During the first 3 months after injury, the prevalence of medical benefit receipt was 47·1 per cent (59·3 per cent among workers and 7·8 per cent among students). During corresponding periods 1 and 2 years before injury, 6·2 and 7·7 per cent respectively of all patients were in receipt of medical benefit (8·1 and 9·8 per cent of workers, and 0·4 and 0·7 per cent of students). Five years after injury, the 3-month prevalence of medical benefits among the 993 patients still alive and of working age was 15·6 per cent among workers with minor injury, 22·3 per cent among moderately injured workers and 40·5 per cent in workers with severe injuries. Corresponding values in students were 9·1, 19·4 and 18·9 per cent. During the entire follow-up interval, patients with severe injury and severe head injury more often received medical benefits (*Fig. 2*). A high level of receipt of medical benefit was observed in all severity groups immediately after the time of injury, declining to a steady-state situation from 1 year after injury and throughout follow-up (*Fig. 2* and *Table 2*). Injury severity and having a severe head injury were independently associated with receipt of benefits; patients with severe injury (ISS over 15) and severe head trauma had the highest estimated level of benefit receipt.

Return to preinjury work activity level

A total of 908 patients worked before the injury, of whom five were excluded (4 died and 1 retired) before the start of follow-up, leaving 903 patients in the final analysis (*Table S2*, supporting information). Of these, 818 patients (90·6 per cent) returned to work after injury within the follow-up period (*Table 3*). Median time to return to work in those with minor, moderate and severe injuries was 1, 4 and 11 months respectively. Patients with severe or moderate injuries were less likely to return to work (preinjury activity level) than those with minor injuries: adjusted HRs 0·36 (95 per cent c.i. 0·29 to 0·44) and 0·75 (0·63 to 0·89) respectively (*Table 3*). Median time to return work for patients with and without severe head injury was 11 and 2 months respectively, with an adjusted HR of 0·44 (0·33 to 0·58) for those with severe head trauma (*Table 3* and *Fig. 3*).

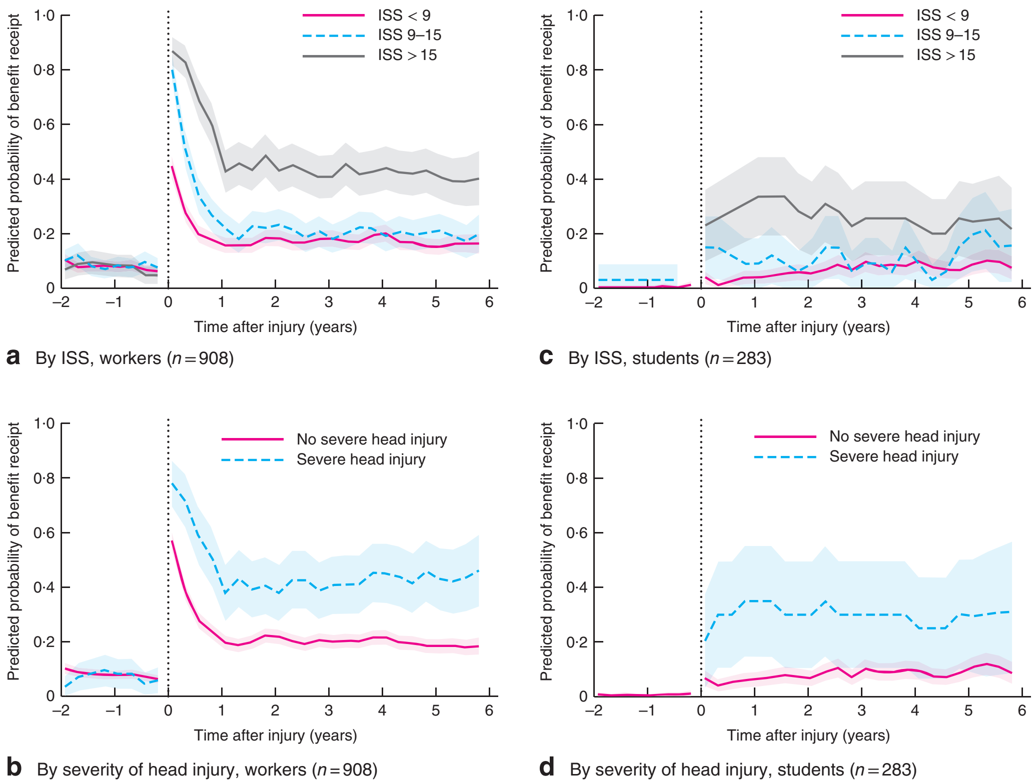


Fig. 2 Predicted probability of receiving sickness/disability benefits before and after injury according to **a**,**c** Injury Severity Score (ISS) and **b**,**d** severity of head injury among **a**,**b** workers and **c**,**d** students. Benefits were assessed in 3-month intervals (benefit or no benefit) and estimates were calculated from population-averaged logistic regression models. Shaded areas represent 95 per cent confidence intervals. Dotted lines indicate the time of injury

Mortality

A total of 1191 patients were eligible for the mortality analyses, of whom 12 (1·0 per cent) died within 30 days and an additional 17 (1·4 per cent) died during the subsequent follow-up period. Patients who died had a median age of 38 (i.q.r. 26–53) years and a median ISS of 25 (9–38). Median ISS was 36 (29–47·5) among patients who died within 30 days compared with 9 (4–22) among those who died later in follow-up. Severe injuries were associated with an increased risk of death (adjusted HR 11·54, 95 per cent c.i. 4·49 to 29·66) compared with minor injuries (*Table 3*). Similarly, the likelihood of death was higher in patients with a severe head injury than in those without (adjusted HR 15·02, 7·04 to 32·05) (*Table 3*).

Table 2 Odds ratios for receiving medical benefits in relation to injury severity

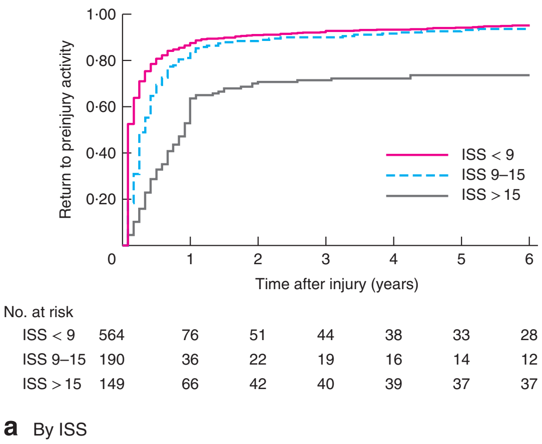
Time after injury (years)	Odds ratio		
	ISS < 9 (*n* = 772)	ISS 9–15 (*n* = 226)	ISS > 15 (*n* = 193)
−2	1·33 (0·94, 1·89)	1·35 (0·77, 2·36)	0·82 (0·42, 1·62)
−1	1·00 (reference)	1·00 (reference)	1·00 (reference)
0 (injury)	8·64 (6·41, 11·66)	34·74 (21·10, 57·19)	45·44 (26·34, 78·41)
1	2·35 (1·71, 3·23)	3·43 (2·07, 5·69)	10·67 (6·19, 18·38)
2	2·87 (2·10, 3·93)	3·66 (2·21, 6·07)	10·05 (5·83, 17·33)
3	3·13 (2·29, 4·29)	2·77 (1·65, 4·64)	9·36 (5·42, 16·15)
4	3·51 (2·57, 4·80)	2·62 (1·55, 4·42)	10·12 (5·86, 17·48)
5	2·56 (1·84, 3·54)	3·67 (2·18, 6·20)	9·17 (5·27, 15·94)

Values in parentheses are 95 per cent confidence intervals. Odds ratios are shown for sickness/disability benefits during the 3 months after injury and during corresponding periods 2 years before injury and from 1 to 5 years after injury, compared with the 3-month period 1 calendar year before injury. ISS, Injury Severity Score.

Table 3 Cox regression analyses of impact of injury severity and head injury on return to preinjury activity and death

	Back to preinjury activity ($n = 903$)			Death ($n = 1191$)		
	No. of events	Unadjusted hazard ratio	Adjusted hazard ratio	No. of events	Unadjusted hazard ratio	Adjusted hazard ratio
Injury Severity Score						
< 9	536	1·00 (reference)	1·00 (reference)	6	1·00 (reference)	1·00 (reference)
9–15	178	0·74 (0·62, 0·88)	0·75 (0·63, 0·89)	6	3·45 (1·11, 10·69)	2·89 (0·92, 9·11)
> 15	104	0·38 (0·30, 0·47)	0·36 (0·29, 0·44)	17	12·16 (4·79, 30·84)	11·54 (4·49, 29·66)
Head trauma						
No	762	1·00 (reference)	1·00 (reference)	12	1·00 (reference)	1·00 (reference)
Yes	56	0·46 (0·35, 0·61)	0·44 (0·33, 0·58)	17	15·42 (7·36, 32·30)	15·02 (7·04, 32·05)

Values in parentheses are 95 per cent confidence intervals.



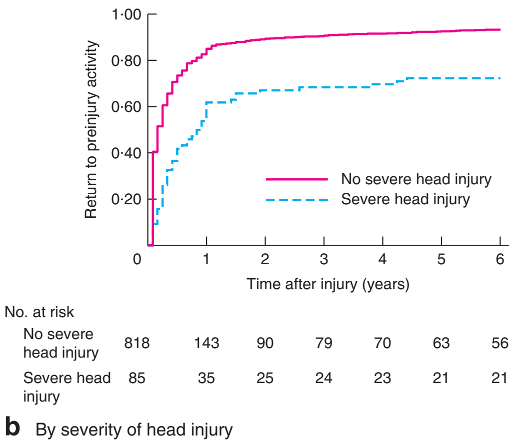


Fig. 3 Kaplan–Meier estimates of return to preinjury activity according to **a** Injury Severity Score (ISS) and **b** severity of head injury. Severe head injury was defined by an Abbreviated Injury Scale-Head score of 3 or higher

Discussion

Patients with minor and moderate injuries had a twofold to threefold increase in the risk of receiving medical benefits throughout the follow-up interval, compared with preinjury levels. Most patients resumed preinjury activity levels within 2 years of injury, but with considerable differences across severity groups. Severely injured patients had a high prevalence of need for medical benefits 5 years after injury and a prolonged time before returning to preinjury activity level. Those with a severe head injury were more likely to be receiving medical benefits.

In a recent Scandinavian publication[30], linkages with national registries were used to assess the long-term effects of morbidity after trauma. There was a substantial increase in the rates of sick leave among injured patients compared with non-injured controls. Although this difference declined during follow-up (36 months), the non-injured controls had lower rates of sick leave many years after the incident[30]. This was explained by an increased prevalence of preinjury sick leave rates, substance abuse, and psychiatric and somatic co-morbidity in injured patients[30]. A similar observation was made in the present study, with a persisting long-term effect of the injury on receipt of medical benefits, although this study population may be considered healthier as they were either in education or working at the time of the injury. There was a considerable post-trauma increase in the number of people receiving benefits, even among those with minor and moderate injuries, which persisted for some 5 years after the trauma. Patients with minor and moderate trauma represented 83·8 per cent of the injured patients in this study. Therefore, even though the prevalence of receipt of medical benefits was lower after minor and moderate trauma, the total medical benefits received by those with minor or moderate injury might be equal to or greater than those received by patients with major injuries. The reason why these apparently healthy people with minor and moderate injuries needed long-term medical benefits was not explored. One possible explanation could be the sustained effects of the injury on physical and psychological health. Previous studies[31,32] indicated that people who have experienced traumatic injuries have more conditions affecting mental health than the general population. In a cohort of severely injured patients, Gabbe and colleagues[19] found that several factors unrelated to the injury itself (such as socioeconomic disadvantage and presence of pre-existing medical, drug, alcohol and mental health conditions) were associated with worse outcomes.

Other studies[33,34] have found that a large number of those with severe injuries (ISS over 15) do not return to preinjury work activity within 12 months after trauma. In studies including patients with moderate and severe injuries (ISS over 9)[8,12], about half of the patients returned to work. In the present investigation, 69·8 per cent of severely injured patients returned to preinjury level of work/education within the extended follow-up period. However, excluding the most severely injured, Fitzharris and co-workers[35] noted a rate of return to work close to 90 per cent, but interestingly found that the majority returned to a different work role. In a study of non-hospitalized injured patients, one-quarter returned to preinjury status, but subsequently deteriorated[36]. The results of these studies, together with the present findings, underline the importance of a long-term functional assessment and suggest that follow-up times should not be dependent on reaching a specific short-term target[36].

Using information about social security benefits as a measure of health and function has its limitations and must be done with caution. Previous studies[37,38] concluded that the duration of disability is not exclusively injury-dependent, but also depends on compensation schemes. In this study, the majority of the working population received medical benefits after trauma, with a steady decline towards the end of the first year. During this first year, the sickness benefits offered by the National Insurance Scheme (with universal benefits covering up to 100 per cent of previous income for all workers) are likely to reflect how injured people in the working population recover and regain their ability to work. This is not the case for non-working students who are not entitled to sickness benefits during the first few months after trauma (*Fig.* 2).

Gradual establishment of a fixed level of patients receiving medical benefits was observed 12–15 months after injury in all severity groups. The timing of this turning point at exactly 12 months could reflect the characteristics of the Norwegian benefit system. After 52 weeks with sickness benefits, the level of compensation is reduced. The level of benefit receipt during the following years may be interpreted as a measure of disability, and was similar for workers and students. Goal-directed early rehabilitation during the first 12 months after injury may represent a window of opportunity for both facilitating faster recovery overall, and improving long-term functional level. For patients with minor and moderate injuries, early rehabilitation does not necessarily imply hospital admission, but frequent ambulatory assessments including healthcare counselling regarding strategies to treat pain, discomfort, problems with reduced mobility when undertaking daily activities, anxiety and depression, and thereby to reduce the effects of trauma[39]. This underlines the need also to include patients with minor trauma in order to understand the full impact of trauma on society[40,41]. A reasonable question for policy decision-makers based on the present findings and those of other studies is whether intensified rehabilitation of patients with minor or moderate trauma is as cost-effective as rehabilitation following major trauma.

The main strength of the present study lies in its population-based design, with complete clinical data collected prospectively from several hospitals covering Central Norway linked with complete individual national registry data. This linkage provides high accuracy and quality owing to the use of the unique identity number assigned to all Norwegians. Use of registry data minimizes the risk of information bias, compared with patient-reported outcome measures[42].

Acknowledgements

The study was preregistered with an analysis plan at Clinical.Trials.gov (NCT02602405) on 11 November 2015. The initial primary outcome measures were time to return to work and time to return to education. During the analysis phase, the authors added the primary outcome receipt of medical benefits as it was found that this variable gave substantial additional important information to describe the course of patients who had sustained traumatic injuries. The secondary outcome measures were added as mortality is important to provide a baseline in comparison with other studies on outcome after trauma.

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authors commit to making the relevant anonymized study data available on reasonable request.

Disclosure: The authors declare no conflict of interest.

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Supporting information

Additional supporting information can be found online in the Supporting Information section at the end of the article.

11. Appendices A – B

Appendix A. Overview and quality of all study variables (n=41) in study 2

Study variable	Valid values *n*	Missing values *n*	Unknown values *n*
Hospital name*	2404	0	N/A
Age	2404	0	0
Gender	2403	1	0
Dominating type of injury	2401	3	6
Mechanism of injury	2404	0	3
Intention of injury	2403	1	5
Glasgow coma scale at scene	2404	0	113
Glasgow coma scale at scene – motor component	2401	3	118
Glasgow coma scale upon arrival in ED	2404	0	10
Glasgow coma scale upon arrival in ED – motor component	2403	1	13
Systolic blood pressure at scene	1569	835	N/A
Systolic blood pressure at scene – RTS category	2402	2	99
Systolic blood pressure upon arrival in ED	2341	63	N/A
Systolic blood pressure upon arrival in ED – RTS category	2399	5	2
Respiratory rate at scene	1070	1334	N/A
Respiratory rate at scene – RTS category	2403	1	179
Respiratory rate upon arrival in ED	1746	658	0
Respiratory rate upon arrival in ED – RTS category	2403	1	23
Number of days on ventilator	2404	0	N/A
Length of stay in main hospital treating patient	2404	0	N/A
Discharge destination	2404	0	0
Glasgow outcome scale at discharge from main hospital	2401	3	217
Survival status after 30 days after injury	2394	10	16
Abbreviated Injury Scale (AIS)	2404	0	0
Injury Severity Score (ISS)*	2402	2	0
New Injury Severity Score (NISS)*	2402	2	0
Highest level of prehospital care provider	2403	1	2359
Pre-hospital intubation	2404	0	2
Pre-hospital thoracic drainage*	2402	2	1
Type of transportation	2404	0	7
Type of first key emergency intervention	2404	0	5
Inter-hospital transfer	2404	0	1
Highest level of in-hospital care	2404	0	5
Date of emergency medical coordination receiving alarm call	2363	41	N/A
Time of emergency medical coordination receiving alarm call	2297	107	N/A
Date of first emergency medical services unit arriving site of injury	2392	12	N/A
Time of first emergency medical services unit arriving site of injury	2214	190	N/A
Date of patient arrival in hospital	2404	0	N/A
Time of patient arrival in hospital	2391	13	N/A
Date of first key emergency intervention	129	2275	N/A
Time of first key emergency intervention	22	2382	N/A

*The table shows the study variables as described in the publication by Ringdal et al [210]. Variables marked with *, were additional variables not included in the Utstein Template [210]. The number of registrations (n=2404) are higher than the actual number of patients (n=2323), because several patients were registered in more than one hospital. Missing values were defined as values not registered and unknown values were registered as such according to the Utstein template.* ***N/A****: not applicable.* ***ED:*** *emergency department.* ***RTS:*** *revised trauma score.*

Appendix B. Overview and quality of clinical study variables (n=37) in study 3

Study variable	Valid values *n*	Missing values *n*
Age	1191	0
Sex	1191	0
Dominating type of injury	1189	2
Mechanism of injury	1191	0
Intention of injury	1190	1
Glasgow coma scale at scene	1191	0
Glasgow coma scale at scene – motor component	1189	2
Glasgow coma scale upon arrival in ED	1191	0
Glasgow coma scale upon arrival in ED – motor component	1191	0
Systolic blood pressure at scene	787	404
Systolic blood pressure at scene – RTS category	1190	1
Systolic blood pressure upon arrival in ED	1174	17
Systolic blood pressure upon arrival in ED – RTS category	1187	4
Respiratory rate at scene	539	652
Respiratory rate at scene – RTS category	1191	0
Respiratory rate upon arrival in ED	885	306
Respiratory rate upon arrival in ED – RTS category	1190	1
Number of days on ventilator	1191	0
Length of stay in main hospital treating patient	1191	0
Discharge destination	1191	0
Glasgow outcome scale at discharge from main hospital	1188	3
Abbreviated Injury Scale (AIS)	1191	0
Injury Severity Score (ISS)	1191	0
New Injury Severity Score (NISS)	1191	0
Pre-hospital intubation	1191	0
Pre-hospital thoracic drainage*	1190	1
Type of first key emergency intervention	1191	0
Inter-hospital transfer	1191	0
Highest level of in-hospital care	1191	0
Date of emergency medical coordination receiving alarm call	1191	0
Time of emergency medical coordination receiving alarm call	1136	55
Date of first emergency medical services unit arriving site of injury	1182	9
Time of first emergency medical services unit arriving site of injury	1091	100
Date of patient arrival in hospital	1191	0
Time of patient arrival in hospital	1185	6
Date of first key emergency intervention	67	1124
Time of first key emergency intervention	8	1183

*The table shows the clinical study variables as described in the publication by Ringdal et al [210] . Variables marked with *, were additional variables not included in the Utstein Template [210].* ***ED:*** *emergency department.* ***RTS:*** *revised trauma Score.*