Assessing patient safety challenges in the initial care of older trauma patients in Norway

A mixed methods approach

by

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Mathias Cuevas-Østrem
Oslo, August 2023

Sammendrag

Denne avhandlingen bygger på ett enkelt premiss: eldre pasienter har rett til akuttbehandling av høy kvalitet når de blir alvorlig syke eller skadde. Traumesystemer gir pasienter de beste sjansene for å overleve med god livskvalitet etter alvorlige skader, også for eldre pasienter. Disse systemene har som mål å skape sømløs informasjons- og behandlingsflyt fra skadestedet til rehabilitering. Planen som beskriver systemet, stiller like krav til prehospitale og inhospitale tjenester over hele landet. Det norske traumesystemet skal ivareta alle pasienter med alvorlige skader, uavhengig av bakgrunn eller hvor de skades. Imidlertid har studier fra sammenlignbare traumesystemer internasjonalt avdekket bekymringsfulle ulikheter i traumeomsorgen for eldre, og spesifikt de med alvorlige hodeskader. Derfor var målet med denne avhandlingen å vurdere om det eksisterer utfordringer knyttet til pasientsikkerhet i den initiale behandlingen av eldre traumepasienter i Norge.

Gjennom analyser av data fra Nasjonalt Traumeregister og fokusgruppeintervjuer med involverte klinikere, har denne avhandlingen identifisert utfordringer knyttet til pasientsikkerhet i det nåværende systemet, men også styrker. To studier fokuserte på epidemiologien til og behandlingen av den generelle traumepopulasjonen, og sammenlignet eldre og yngre voksne. De påfølgende to studiene fokuserte på pasienter med isolerte hodeskader som ble innlagt på ikke-nevrokirurgiske akuttsykehus. Vi undersøkte pasientforløp og hvilke faktorer som påvirket beslutningen om å overføre pasienter mellom sykehus, inkludert rollen til alder og tidligere sykdommer.

Våre studier avdekket i hovedsak utfordringer knyttet til prehospital behandling. Eldre traumepasienter fikk sjeldnere avansert prehospital behandling, til tross for sammenlignbar skadealvorlighetsgrad. De ble sjeldnere møtt av et team med lege og paramedisiner, fikk sjeldnere avanserte intervensjoner og ble sjeldnere transportert med luftambulanse. Ved sykehusinnleggelse ble de sjeldnere møtt av et traumeteam og hadde lavere innleggelsesrater i traumesentre.

Vi fant at mer enn en tredjedel av eldre traumepasienter hadde alvorlige hodeskader. Eldre pasienter ble sjeldnere intubert før ankomst på sykehus, til

tross for en Glasgow Coma Scale score under 9. Videre observerte vi at eldre pasienter med isolerte moderate til alvorlige hodeskader i større grad ble henvist til ikke-nevrokirurgiske sykehus som primærsykehus, sammenlignet med yngre pasienter. Faktorer som alder, tidligere sykdommer og funksjonsnedsettelser før skaden, reduserte sannsynligheten for overføring til et nevrotraumesenter. Den komplekse beslutningsprosessen rundt overføring var også sårbar for kommunikasjonsfeil.

Imidlertid identifiserte våre studier også viktige styrker ved det nåværende systemet. Når et traumeteam ble aktivert ved sykehusinnleggelse, var det få klinisk signifikante forskjeller i behandlingen mellom unge og eldre voksne. Og klinikere forsøkte å ta pasient-sentrerte beslutninger om hvem som skulle overføres for spesialisert nevrotraumebehandling basert på individuelle pasienters helsetilstand og sjanser for positive resultater.

Dette arbeidet er den første større studien av pasientsikkerhetsutfordringer for eldre traumepasienter i Norge. Arbeidet har bekreftet at utfordringer knyttet til pasientsikkerhet, som er vist i studier fra andre land, også eksisterer her, i en skandinavisk sammenheng preget av et offentlig finansiert helsevesen. Videre har det gitt ny innsikt om bruken av lege-paramedisiner-team i omsorgen for eldre traumepasienter. Det har også bidratt med kunnskap om behandling av eldre pasienter med hodeskader i velutviklede traumesystemer, og dermed styrket et internasjonalt forskningsfelt i utvikling.

Å avdekke problemer innenfor et system fungerer som en grunnstein for å løse dem. I dette perspektivet belyser denne avhandlingen ikke bare eksisterende utfordringer, men legger også kursen for fremtidig innsats: det bør forskes videre på bedre systemer for utkall av prehospitale ressurser, beslutningsstøtte for prehospitalt personell og forbedret kommunikasjon mellom sykehusene knyttet til overføring av hodeskadepasienter. I en nært forestående framtid hvor befolkningen eldes og presset på helseressursene øker, blir viktigheten av god ressursallokering og god behandling av eldre enda mer påtrengende. Disse målene er oppnåelige gjennom fortsatt forbedring av traumesystemet.

Summary

This thesis builds on one simple premise: older patients have the right to high-quality emergency care when critically ill or injured. Optimal chances of survival and good quality of life after severe injuries are primarily achievable through trauma systems, also for older people. These systems mandate requirements for both prehospital and in-hospital services, aiming to establish a seamless transition of information and care from the incident site to rehabilitation. The Norwegian trauma system embraces all patients regardless of their background or the location of their injuries. However, studies from comparable trauma systems internationally have found concerning disparities in care for older trauma patients in general and patients with head injuries in particular. The aim of this thesis was, therefore, to assess whether patient safety challenges exist in the initial care of older trauma patients in Norway.

Through analyses of data from the national Norwegian Trauma Registry and focus group interviews with involved clinicians, this thesis identified patient safety challenges in the current system, but also strengths. Two studies focused on the epidemiology and management of the general trauma population and compared older and younger adults. The subsequent two studies focused on patients with isolated traumatic brain injuries (TBI) admitted to non-neurosurgical acute care trauma hospitals. We investigated care pathways and which factors influenced interhospital transfer, including the role of age and comorbidities.

Our studies predominantly revealed prehospital challenges, with older trauma patients receiving less advanced prehospital care despite comparable injury severity. Notably, they received prehospital doctor/paramedic team attendance, advanced interventions, and air ambulance transportation less frequently. Upon hospital admission, they were less often met by a trauma team and showed lower trauma center admission rates. Older patients showed an almost 5-fold 30-day mortality rate.

We found that more than every third of older trauma patients had a severe head injury. Older patients underwent prehospital intubation less frequently despite Glasgow Coma Scale scores <9. Furthermore, we observed that older patients

with isolated moderate-to-severe TBI were more frequently directed to non-neurosurgical hospitals for primary admission than their younger counterparts. Factors such as advanced age, comorbidities, and preinjury functional impairments contributed to a reduced probability of interhospital transfer to a neurotrauma center. The intricate transfer decision process exhibited susceptibility to communication errors.

However, our studies also identified important strengths of the current system. When a trauma team was activated upon hospital admission, there were few clinically significant management differences between young and older adults. And clinicians tried to make patient-centered decisions about whom to transfer for specialized neurotrauma care based on individual patients' health statuses and chances of favorable outcomes.

This undertaking is the first large study to assess patient safety challenges for older trauma patients in Norway. It has confirmed that patient safety challenges comparable to those found in studies from other countries also exist here, in a Scandinavian setting characterized by a publicly funded healthcare system. Moreover, it has unveiled novel insights about the use of doctor/paramedic teams in the care of older trauma patients. And it has contributed information about traumatic brain injury management of older patients within mature trauma systems, contributing to an emerging research field internationally.

Identifying problems within a system serves as a stepping stone for their resolution. In this light, this thesis not only underscores existing challenges but also charts the course for future improvement efforts: dispatch of prehospital resources, decision support for prehospital personnel, and improved interhospital communication regarding TBI transfer. As populations are aging and healthcare resources face increasing constraints, the imperative to optimize resource allocation and improve patient outcomes becomes even more pronounced. Through continued refinement of the trauma system, these goals remain attainable.

List of publications

This thesis is based on the following studies and the papers they resulted in, which will be referred to by their Roman numerals:

I. **Epidemiology of geriatric trauma patients in Norway: A nationwide analysis of Norwegian Trauma Registry data, 2015-2018. A retrospective cohort study.**
Cuevas-Østrem M, Røise O, Wisborg T, Jeppesen E. *Injury*. 2021;52(3):450-9.

II. **Differences in time-critical interventions and radiological examinations between adult and older trauma patients.**
Cuevas-Østrem M, Wisborg T, Røise O, Jeppesen E. *J Trauma Acute Care Surg*. 2022;93(4):503-12.

III. **Care pathways and factors associated with interhospital transfer to neurotrauma centers for patients with isolated moderate-to-severe traumatic brain injury: a population-based study from the Norwegian Trauma Registry**
Cuevas-Østrem M, Thorsen K, Wisborg T, Røise O, Helseth E, Jeppesen E. *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine*. 2023;31(1):34.

IV. **Decision-making in interhospital transfer of traumatic brain injury patients: exploring the perspectives of surgeons at general hospitals and neurosurgeons at neurotrauma centres**
Cuevas-Østrem M, Wisborg T, Røise O, Helseth E, Jeppesen E. *Submitted 2023.*

The protocol of this thesis was published early in the project period and is not included in the thesis (1). The goal with publishing the protocol was to strengthen accountability through transparency.

List of abbreviations

AAM – Advanced airway management

ACS-COT – Amereican College of Surgeons Committee on rauma

ACTH – Acute care trauma hospital

AIS – Abbreviated Injury Scale

ASA-PS – American Society of Anesthesiologists Physical Status

CCU/HDU – Critical care and high dependency units

CD – Chest decompression

CI – Confidence Interval

CT – Computed tomography

ED – Emergency department

Edf – Effective degrees of freedom

EMCC – Emergency Medical Communications Center

EMS – Emergency Medical Services

EMT – Emergency Medical Technician

G1 – Group 1

G2 – Group 2

GAM – Generalized Additive Model

GCS – Glasgow Coma Scale

HEMS – Helicopter Emergency Medical Services

Index – Norwegian Index for Medical Emergencies

ISS – Injury severity score

MODS – Multiple Organ Dysfunction Syndrome

NISS – New injury severity score

NTC – Neurotrauma center

NTR – Norwegian Trauma Registry

OR – Odds Ratio

TARN – Trauma Audit and Research Network

TBI – Traumatic brain injury

WHO – World Health Organization

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1 Introduction and rationale

In the spring of 2017, I began my internship after medical school, and I thrived with frequent rotations to various departments, continuously learning new things. However, it surprised me to recurrently encounter older patients with severe injuries who had not been considered trauma patients. During the rotation to the public casualty clinic, I treated one such patient who left a mark on me and made me wonder whether older people received optimal treatment when injured. The case encapsulated some of the clinical and ethical challenges characteristic of older trauma patients and was, unfortunately, not unique (2).

It was a weekday morning when an ambulance brought in a woman in her mid-70s under the label "Sudden onset of neurological symptoms", accompanied by her husband[1]. She had lost the ability to speak, so he calmly yet efficiently explained what had happened, sensing the urgency of the situation. I mirrored his demeanor to convey understanding and agreement with his unspoken concerns. I was genuinely worried. Despite my relative youth and inexperience, my early interest in trauma care made me suspect a severe diagnosis.

The husband explained that his wife had stumbled on the bathroom floor an hour and a half before the onset of symptoms but managed to regain her footing and come downstairs for breakfast. However, shortly after breakfast, she started struggling with words, speaking incoherently. He called for an ambulance. Initially, the paramedics considered a stroke the most likely diagnosis and consulted the on-call neurologist. The neurologist connected the preceding fall to her symptoms and redirected them to the casualty clinic.

By the time she arrived at the clinic, she could only respond to my questions with monosyllabic answers devoid of meaning. She sat half-sitting on the stretcher in an examination room with closed eyes, yet seemingly aware of her surroundings.

I conducted a targeted physical and neurological examination and proceeded with a computed tomography (CT) scan of her head, which confirmed my suspicions—a significant intracranial bleed. During the physical examination,

[1] Details are altered to preserve anonymity.

I had also discovered a sizable hematoma stretching from her buttocks to her right thigh—an unexpected finding considering the low-impact fall. Before contacting the hospital, I sought additional background information. The husband confirmed that she took anticoagulant medications for atrial fibrillation and had a minor stroke ten years earlier, which she had recovered from without sequelae. She received no home care, drove regularly for grocery shopping, and actively cared for her grandchildren. In his words, she was in good health. By this point, over two hours had passed since the fall, and her condition was deteriorating.

I consulted the on-call neurosurgeon, who, upon reviewing the CT images, hearing the patient's history, and considering her background and age, recommended "conservative treatment", i.e., to refrain from surgery because it would not improve a dismal prognosis. I found myself taken aback by how readily he reached this decision through a telephone consultation. Could there really be nothing to do to improve her outcomes? The patient was admitted to the hospital, a short distance away.

My responsibilities were fulfilled, but a mix of thoughts lingered. I was satisfied with the efficient care we had provided, yet I could not shake the feeling that a better outcome could have been achieved if everything had proceeded optimally from the start.

Later, her hospital records revealed that her level of consciousness rapidly declined after hospital admission, and a follow-up CT scan showed an expansion of the hematoma. She died shortly after.

This case illustrates several key characteristics of older trauma patients. Low-energy falls can result in significant trauma with dire outcomes. Undertriage, i.e., failure to admit a trauma patient to a hospital with a pre-alerted trauma team, can occur when it becomes challenging to connect the dots; the symptoms were initially mild and mimicked a stroke diagnosis. This made it difficult to attribute the symptoms to an unwitnessed fall that had occurred earlier. Additionally, the patient's loss of speech placed reliance on information provided by next-of-kin. Further, it compromised her autonomy in treatment decisions. The presence of comorbidities and the use of anticoagulants were significant risk factors in this case, contributing to the fatal outcome. The head is a commonly injured body region, with a high risk of mortality and reduced functional outcomes. Finally, the lack of streamlined care resulted in time being wasted when immediate access to specialized care could have potentially resulted in a different outcome.

Was her death avoidable? Could my experience of meeting older trauma patients with multiple and/or severe injuries outside the trauma system be representative of a system-wide problem concerning a large group of patients? Were emergency medical communications centrals (EMCCs) capable of recognizing severely injured trauma patients, or did consequential errors start there? Were expectations of poor outcomes leading to a passive approach, making direct and indirect (e.g., deliberate transport to lower-level care facilities) treatment-limiting decisions common for older people? Did anyone question these decisions? How did older trauma patients do in the Norwegian trauma system, really? These were questions both myself and those who eventually became my supervisors pondered. It led us to set out this investigation.

The historic backdrop is important: In Norway, as in comparable countries, trauma is the leading cause of death and disability in young people (<45 years) (3). Trauma systems have successfully been designed and implemented to counteract this very problem, so more people survive (3-6). Consequently, triage tools were developed to identify injured patients based on typical characteristics in younger patients. However, the Norwegian trauma system and Norwegian healthcare legislation embrace all patients regardless of their background or where they became injured (7, 8). So, over time, when the general population, and thus the trauma population, became older, potential patient safety issues started to become apparent (9, 10). The typical trauma patient was no longer a young male injured in high-energy accidents, but increasingly an older person injured in low-energy falls (9).

The core challenge is the mismatch between the characteristics older patients exhibit and the criteria incorporated in the trauma system design to identify patients with severe injuries. Precise identification is necessary to start the trauma chain of survival (11). In the older population, injury mechanisms are typically low-energy, injuries frequently occult due to an atypical and delayed physiologic response (compared to younger adults, that is), and the margins are small due to limited physiologic reserves (12-16). Consequently, this led to problems.

The most tangible problem is the poorer outcomes older trauma patients experience. Unadjusted mortality rates are approximately 2-4 times higher for older than young adults (17-19). Worryingly, an extensive body of evidence point to differences in management that may be associated with the poor outcomes: In 2017, a seminal report was published by the UK Trauma Audit and Research Network (TARN), titled "Major Trauma in Older People" (2). The report called *mayday* regarding the risks older people faced of not receiving care according to guidelines when they sustained severe injuries: *"The most important underlying finding of this report is the difficulty that current systems appear to have in the early identification of older patients with major trauma"*. The report's findings added to a pre-existing body of knowledge about differences between adult and older trauma patients: Studies had identified a high risk of undertriage to a trauma team upon hospital admission (20-22) and risk of nontransfer to a higher level of care (23, 24) or delayed transfer (25). Patients with traumatic brain injury (TBI) were managed by more junior doctors and experienced increased time to a head CT (24). But the comprehensive TARN report established evidence of management differences throughout the whole trauma system.

As the Norwegian trauma system shares similarities with systems internationally, we had reason to expect patient safety risks for older trauma patients in Norway too. The fact that older people constitute the fastest-growing segment in most European countries (10, 26) prompts increased attention to the challenges faced by this group, although the challenge has been warned about for three decades (17, 27, 28). Therefore, this research effort aimed to comprehensively investigate potential patient safety risks in the initial care of older trauma patients in Norway. This will serve as a stepping stone for future improvement efforts.

This thesis comprises four studies about trauma care for older trauma patients in the Norwegian trauma system. In such system-focused research, it would have been easy to neglect the perspective of individual patients. However, within the Norwegian Trauma Registry (NTR) dataset I have accessed, consisting of more than 50,000 patient records, one of those records belonged to the case in which I played a minor role. Her case served as a reminder of the narratives lived by trauma patients and their families (29), sparked the idea for this research project, and reinforced the ultimate purpose of this research – to strengthen patient safety for older trauma patients in Norway.

2 Background

2.1 Definitions

2.1.1 Definition of trauma

Trauma is defined as an *"injury to living tissue caused by an extrinsic agent"* that occurs when the tissue's tolerance capabilities are exceeded by a mechanical force, heat, or another form of energy (30). This thesis focuses on the physical aspects of trauma, and the mental health aspects are beyond its scope. Following this definition, injuries can range from minor to major severity. From simple cuts to extensive tissue damage in several body regions, with consequences varying from negligible to devastating (3, 31). In the literature, trauma research primarily focuses on the severe end of the injury spectrum, commonly referred to as 'major trauma' or 'severe trauma'.

Thompson et al. have put forth a descriptive definition of major trauma. It captures the aspect of severity and recognizes vulnerable populations: *"Significant injury or injuries that have potential to be life-threatening or life-changing sustained from either high energy mechanisms or low energy mechanisms in those rendered vulnerable by extremes of age."* (32). This definition is derived from a Delphi technique, thus reflecting what several experts put into the term 'major trauma'. It serves a purpose in trying to unify what is meant when communicating in the clinical setting. However, it lacks objective criteria for determining whether injuries are indeed life-threatening or life-changing, relying instead on the clinician's prerequisite knowledge and understanding of trauma. So how can severity be measured?

Several measures of trauma severity exist (33). The most commonly used are anatomical measures such as the Injury Severity Score (ISS) and the New ISS (NISS), both derived from the Abbreviated Injury Scale (AIS) (34-37). The AIS designates a body region-specific code for all injuries. The AIS assigns all injuries with a severity score within the range of 1 (minor) to 6 (maximal). The ISS is calculated as the sum of the square of the highest AIS severity scores of the three most severely injured body regions. The NISS incorporates the three most severe injuries irrespective of body regions. AIS-based scoring systems have been associated with various outcomes, including mortality and in-hospital resource use (37). The ISS or NISS is frequently used to establish a threshold for defining severe injury, whether for study or registry inclusion, with an ISS >15 being the most commonly applied threshold (38). It is important to recognize certain limitations of these anatomical definitions. They are typically calculated retrospectively long after discharge or death, requiring all available information from clinical examination, radiological imaging, and potentially autopsies, which limits their utility in clinical settings. Furthermore, their accurate application requires a solid understanding of the scoring system. Consequently, their role is primarily for research and benchmarking.

Therefore, a clinically available measure of injury severity is needed to detect severe injuries as early as possible to provide timely treatment. A composite four-step algorithm forms the basis of most prehospital triage tools. They comprise physiological measures, the anatomical extent of injuries, mechanisms of injuries associated with a high risk of being injured, and patient risk factors associated with an increased risk of worse outcomes (39, 40). A hit in any such criteria in an injured person warrants suspicion of severe injuries. A hit in physiological criteria is most sensitive for severe injuries (Figure 1). The full Norwegian tool is shown in Appendix 1.

Criteria to suspect severe injury

Physiology	
Respiratory rate	<10 or >29/min, or need for ventilatory support (<20 for children < 1 year old)
Oxygen saturation (SpO2)	<90% without O2
Heart rate	>130/min
Systolic BP	≤90 mm Hg
GCS	≤13
Severe hypothermia without normal circulation	

Figure 1: Physiologic criteria used to detect severely injured patients.

Modified with permission from the Norwegian National Advisory Unit on Trauma (7).

In this thesis, the term *trauma* carries the same connotations and implications as are captured by the definition proposed by Thompson et al. When necessary, objective definitions of trauma are applied, such as in the context of study inclusion criteria. The term severe injury is sometimes used interchangeably with trauma.

2.1.2 Definition of an older person

The World Health Organization (WHO) and the United Nations UN define older people as individuals who are over 60 years of age (41, 42). The Norwegian Institute of Public Health applies a threshold of 65 years or older (43), which aligns with most trauma research (44). From a biological perspective, defining a specific age cut-off to demarcate older persons is conceptually flawed, as aging is a continuous and vastly heterogeneous process (45). Furthermore, chronological age only captures one aspect of the multifaceted aging process, and other measures, such as frailty, may better reflect an individual's overall aging and health status (46). Nevertheless, establishing a defined population allows for comparisons across different systems, regions, and time periods, and age remains the most readily accessible measure.

Although the evidence supporting the most-used cut-off of 65 years is limited , evidence suggests a substantial change in trauma outcomes around this age (2, 47). In a sample of severely injured patients from a high-quality population-based trauma registry in Victoria, Australia, both mortality and reduced functional outcomes increased when patients were 60-70 years old (Figure 2) (47). Therefore, in accordance with convention and observational evidence, this thesis adopts the age of 65 years or older as the definition of an older person.

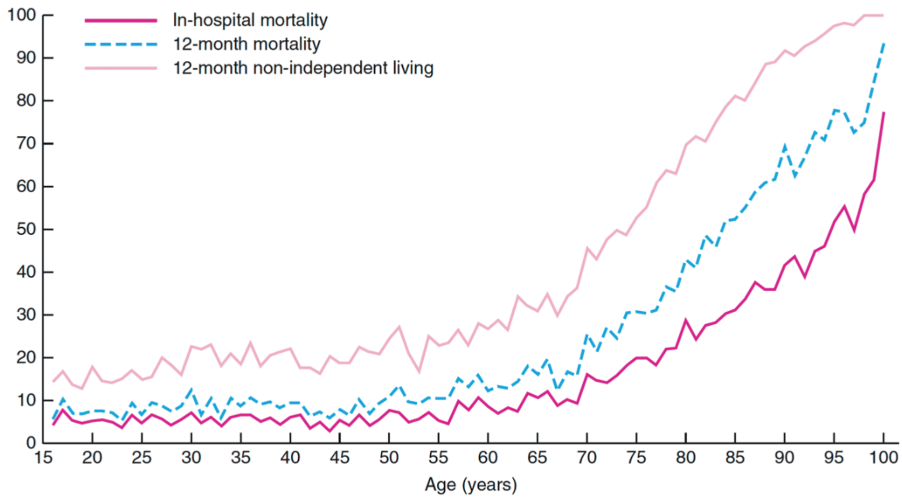

Figure 2: In-hospital mortality, 12-month mortality and 12-month functional outcomes after major trauma according to age.

Non-independent living was used for functional outcome, defined as Glasgow Outcome Scale – Extended score of 4 or less. Values shown at 100 years include all patients with major injury aged 100 years or more. *Reused* from Beck et al. (47) under the terms of the Creative Commons CC BY license.

It is important to note that the term *geriatric trauma* has previously been used to describe the older trauma population, including in this project. However, this term is now largely abandoned as it carries a broader connotation than simply denoting old age (48). The journal of the British Geriatric Society, Age and Ageing, stresses a conscious use of language and recommends the term '*older people*' (49).

2.2 Epidemiology of trauma

The following chapter presents the epidemiology of trauma, focusing on older patients. TBI is sometimes emphasized because of its importance in *Studies III and IV*.

2.2.1 Incidence and prevalence

Incidence is a measure of new cases that develop in a defined population during a specified period of time (50). It is a valuable measure of the burden of a disease, the development of trends, and for planning of resources. To calculate incidence rates, a clear definition of the disease and the size of the population at risk is needed. Trauma incidence rates will be highly dependent on the chosen trauma definition and to what extent prehospital deaths are registered, which account for up to 50-86% of injured patients (51-53). As trauma patients are not diagnosed with one "trauma code" in clinical coding frameworks such as ICD-10, but rather with several codes for individual injuries, identifying the true trauma population from general patient registries is challenging. Disease-specific clinical quality registries with a high patient coverage may enable incidence rate calculations, but few registries cover whole populations (54). To my knowledge, national incidence rates for trauma have not been reported in Norway, although studies of populations in single regions or with specific conditions exist (55, 56).

Prevalence refers to the proportion of a population who have a specific characteristic in a given period of time. The prevalence of older trauma patients is not straightforwardly compared across trauma systems, as different trauma registries worldwide apply different definitions of trauma. Temporal prevalence trends within databases allow for internal comparisons and results from multiple studies and reports tell the same story: the prevalence of older patients is increasing faster than populations are aging. For example, the proportion of severely injured older patients increased from 8% to 27% from 1990 to 2013 in the UK (ISS>15, age ≥75) (9), from 25% to 37% from 2007 to 2016 in Victoria, Australia (median ISS 17, age ≥65 years) (47), and from 23% to 30% from 2003 to 2009 in the USA (admitted to Level I and II trauma centers, ≥65 years) (57). It has been discussed whether the increase to some extent may be caused by changes in practice, such as increased imaging rates with CT (9, 47) and increased focus on the group and comprehensive identification and registration of undertriage (58).

The incidence of TBI in Europe (all ages, all severities, regional-level studies) ranged from 83.3/100,000 to 849/100,000 per year (59). The incidence of hospital-admitted severe TBI in a national sample from Norway was 4.1/100,000 in 2010 (55). The frequency of hospital discharges for TBI is highest among old and young/adolescent patients (Figure 3) (55, 60, 61).

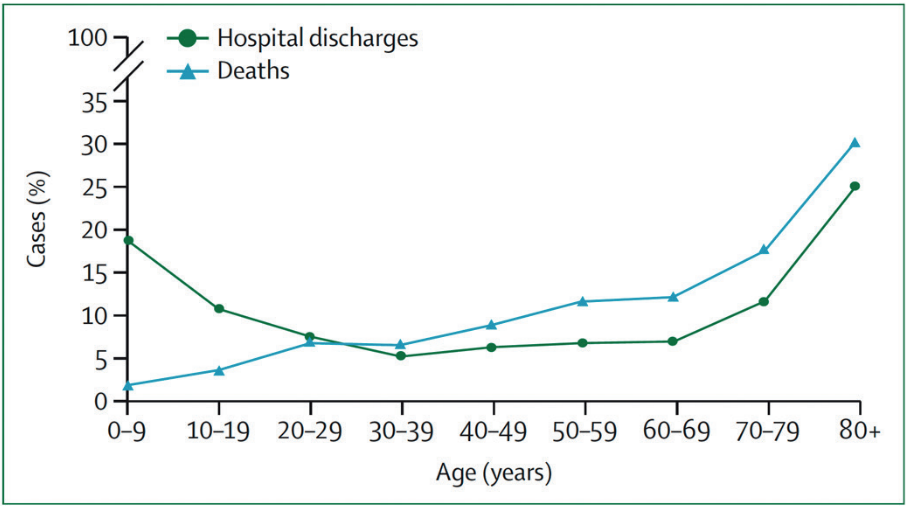

Figure 3: Estimated frequency of hospital discharges and deaths in cases of traumatic brain injury by age group in Europe.

Figure reused from Maas et al. with permission from Elsevier (62).

2.2.2 Demography

Populations are aging globally; according to the WHO, all countries in the world face an increase in both the numbers and the proportion of older people in the population (42). High-income countries have come the longest way and already have old populations, with Japan as the leading country with 30% of the population over 60 years (42). Within the European Union, the projected increase in the proportion of people ≥65 years is from 20% in 2020 to 29% in 2050, a slightly higher proportion than the Norwegian projections from 16.5% to 26% (26, 63). Population aging is primarily caused by improved healthcare and lower birth rates (42).

As a consequence of aging populations, trauma patients' ages are increasing. The average age varies between countries and the definition of trauma and inclusion criteria, but several studies describe a temporal increase (9, 12). Furthermore, with increasing age, the proportion of females increase in the general population and among trauma patients, and surpasses that of male trauma patients between 70 to 85 years of age (2, 47, 64, 65)

2.2.3 Risk factors

In epidemiology, risk factors for developing diseases are identified to mitigate risk through preventive measures. This strategy is adopted by trauma system thinking (66, 67). Characteristics associated with a high trauma prevalence can be considered risk factors. Socio-demographic factors, such as mental health problems, drug misuse, unstable housing conditions, partner violence, and incarceration are consistently identified as risk factors for severe and recurrent injuries in the literature (62, 68). Some age groups possess extra risk. A study from the German trauma registry TR-DGU showed an excess risk from 51 years that markedly increased from 68 years of age, in addition to the age group 18-27 years (69). Geographical risk factors have also been identified, with an increased mortality risk in rural areas (70).

Preventive measures can be targeted to high-risk populations identified by specific injury mechanisms in particular populations. These can be of interest because they constitute many patients, such as older patients who fall (9, 71), or because of high associated severity, such as young adults in high-speed car crashes (72). Risk factors for sustaining severe injuries from low falls are many, such as frailty, comorbidities, and osteoporosis (73). In the older population, altered sensation, vision, and reaction times, the use of medication such as antihypertensives, sedatives, and polypharmacy in general, as well as acute and chronic conditions, may contribute to the risk of sustaining injuries (74).

Most TBIs are also caused by traffic-related accidents or falls, and age, alcohol misuse, and frailty are considered some of the risk factors for TBI (62).

2.2.4 Clinical features

Knowledge about a condition's typical clinical features helps identify patients with the condition. Triage tools incorporate knowledge about clinical features for this purpose (Chapter 2.1.1). It is well-established that older patients exhibit different clinical features than younger adults when injured, making specific knowledge key to recognizing severely injured older patients.

2.2.4.1 Physiology

Patients' physiologic responses to trauma may be delayed and/or atypical compared to younger adults (74). This relates to age-related changes in different organ systems, and, if present, disease- and medicine-related changes too. Examples of changes in organ systems with corresponding implications for trauma management are listed in Table 1.

Table 1: Physiologic changes in geriatric trauma patients. Reused from UpToDate with permission from Wolters Kluwer (74).

Organ system	Changes	Implications
Pulmonary	Decreased vital capacity Decreased forced expiratory volume Smaller alveolar surface area Decreased chest wall compliance	Reduced respiratory reserve
Cardiac	Decreased cardiac output Decreased sensitivity to catecholamines	Reduced cardiac reserve Vital signs may not reflect severity of injury
Renal	Decreased glomerular filtration rate Decreased renal mass	Increased risk of traumatic injury Increased risk of contrast-induced nephropathy Increased susceptibility to fluid overload Reduced clearance of certain medications

Hepatic	Decreased hepatic function	Decreased clearance of certain medications
Gastrointestinal	Diminished pain sensation Increased laxity of abdominal wall musculature	Potential for significant abdominal injury without peritoneal signs
Immune	Impaired immune response	Increased risk of infection
Musculoskeletal	Loss of muscle mass Osteoporosis	Increased risk of fracture
Neurologic	Decreased autoregulatory capability Brain atrophy	Increased susceptibility to injury from decreased cerebral perfusion Increased risk for occult injury

Particularly associated with these changes are the risk of occult shock and CNS injury; vital signs may be within normal-range values as defined by triage tools (14, 15). But these are false negative results. Brain atrophy leads to more space inside the skull, so it can bleed more before pressure on intracranial structures gives symptoms. With preexisting hypertension, blood pressure in the lower 'normal' range can represent a significant drop from habitual pressures and mask hypoperfusion from blood loss. Regular use of medications such as beta blockers can inhibit the hypovolemia-induced pulse increase. Consequently, the on-scene clinical investigation can be confounded (44).

2.2.4.2 Anatomy

The anatomical extent of injuries has been found to show age-related patterns, with older people more frequently experiencing severe (AIS≥3) head and pelvis- and lower-extremity injuries than younger patients (12, 75). Whether older patients are more susceptible to concurrent injuries to two or more body regions or specific patterns of polytrauma, such as head, distal upper extremity fractures, and neck of femur fractures, which is a likely combination from a low fall, has not been adequately elucidated.

2.2.4.3 Other

Older patients show a higher rate of blunt trauma than younger adults (12, 74). The most frequent mechanisms of injury are low-energy falls, increasing with increasing age, followed by traffic-related injuries and high-energy falls (2, 12, 47, 65).

Cognitive impairments become increasingly prevalent with advancing age, with consequences for anamnesis. This may lead to reliance on information from next of kin or healthcare personnel (44).

Polypharmacy may further alter the clinical presentation. Antithrombotic medications are increasingly common with advanced age and increase bleeding risks (44).

Frailty encompasses accumulated deficiencies in multiple biological systems throughout one's lifetime. It represents an overall reduced physiologic reserve capacity and ability to maintain homeostasis. One of the clinical presentations is reduction in functional abilities. Frailty leads to vulnerability to withstand external stressors (46). Frailty is associated with mortality after trauma, and predicts outcomes better than age (16, 76). The concept is emerging as central for improving trauma care for older patients, particularly individualized decision-making (16, 77).

Figure 4 illustrates the relationship between frailty and trauma. It shows the consequences of an external stressor (e.g., trauma) on the trajectories of patients with or without frailty (Y axis).

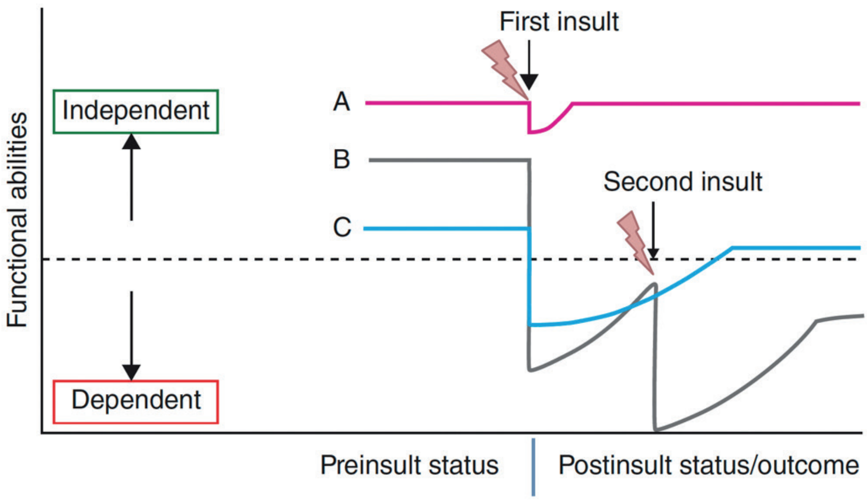

Figure 4: The relationship between frailty and trauma.

The figure shows the clinical trajectories for three patients exposed to trauma. The Y-axis shows the degree of frailty. Patient A has no preinjury frailty and suffers minor trauma. Postinjury recovery is swift, and full capacity is regained. Patient B has mild frailty and suffers major trauma (the depth of the line at insult). Moreover, severe complications that occur during recovery (second insult, e.g., stroke or severe pneumonia) lead to further deterioration. Postinjury recovery is prolonged and preinjury functional ability is never regained. Patient C has moderate frailty and suffers major trauma. However, high-quality pre- and in-hospital care avoids depletion of physiological reserves (e.g., by avoiding hypothermia, shock, and delirium). Recovery takes longer time than for patient A and preinjury functional ability is not fully regained. Reused and modified from Desseerud et al. (78), based on Clegg et al. (79) with permission from Oxford University Press.

2.2.5 Outcomes

Older trauma patients are particularly susceptible to the consequences of trauma due to their reduced anatomical and physiological reserves (73). Mortality has historically been the most important outcome measure in trauma, but as mortality rates have decreased, an increased focus has been put on the quality of survival. Furthermore, an understanding of different expectations of outcomes between young and old people has led to a focus on *"measuring what matters"* (80). A standard set of health outcome measures for older persons was recently developed (81) but is not integrated in routine trauma benchmarking. They used a modified Delphi technique and focus group interviews involving older persons and international experts. It showed that being able to regain social and community participation, live independently, and in general have a good quality of life were considered more important than mere survival.

2.2.5.1 Mortality

Mortality increases with advancing age (Figure 2) (2) and advanced age has been identified as an independent mortality risk factor in a systematic review (82). Key risk factors for mortality are increasing age (47, 82) and injury severity (82), frailty (16, 76, 83), and comorbidity (84). Age (85) and comorbidity are included in several survival prediction models (86, 87). On direct comparison between young and old adults, e.g., 16-64 and ≥65 years, crude mortality rates are 2-4 times higher for older trauma patients, although exact mortality rates are case-mix dependent (18, 19).

The most common causes of death after trauma are exsanguination (particularly in prehospital deaths), central nervous system injuries, airway obstruction, and sepsis/multiple organ dysfunction syndrome (MODS), whereas the internal rank of the different causes will vary between locations and systems (51, 88). The proportion of patients who die in the prehospital phase range from 52% to 86% in the Scandinavian setting (51-53). Older people are more likely to survive to hospital admission (51, 52) and subsequently to die late (>7 days), particularly from MODS (51, 89). Withdrawal of life-sustaining treatment is also a considerable cause of death among hospital-admitted older adults, reaching 65% of patients ≥70 years in a study from a Dutch Level I trauma center (90).

TBI poses a high mortality risk in older adults (Figure 2) (62, 91).

2.2.5.2 Functional outcomes

Functional outcomes include but are not restricted to physical and mental well-being, independence in activities of daily life, and the ability to work. Generic scales (e.g., EQ-5D) and disease-specific scales (e.g., Trauma Quality of Life [general trauma population] or Glasgow Outcome Scale Extended [TBI]) have been developed. Population-based studies from the Victorian State Trauma Registry in Australia have shown that older people were at increased risk of poorer functional outcomes than younger adults regarding postinjury mobility, self-care, usual activities, and pain (92, 93). Other studies have confirmed similar findings in general trauma populations (94) and TBI populations (95, 96).

2.2.5.3 Other outcome measures

Length of hospital and ICU stay, discharge destination, and complications are important outcome measures from a system- and patient perspective. A recent systematic review and meta-analysis identified an increased risk for frail older patients of experiencing longer hospital stays, discharge to other places than home, and in-hospital complications (97). Noticeably, frailty was a stronger predictor of adverse outcomes than age, which has implications for the importance of frailty screening in older trauma patients.

2.3 Trauma systems

2.3.1 Description of concept

The fundamental principle of trauma systems is: *"The needs of all injured patients are addressed wherever they are injured and wherever they receive care."* (66). The overarching goal is to reduce the burden of injury for the individual and society by coordinating and optimizing resources throughout the entire care continuum, spanning from prevention to death or survival (Figure 5) (66, 67). Figure 5 also shows examples of trauma system performance measures, which will be discussed in Chapter 2.5.

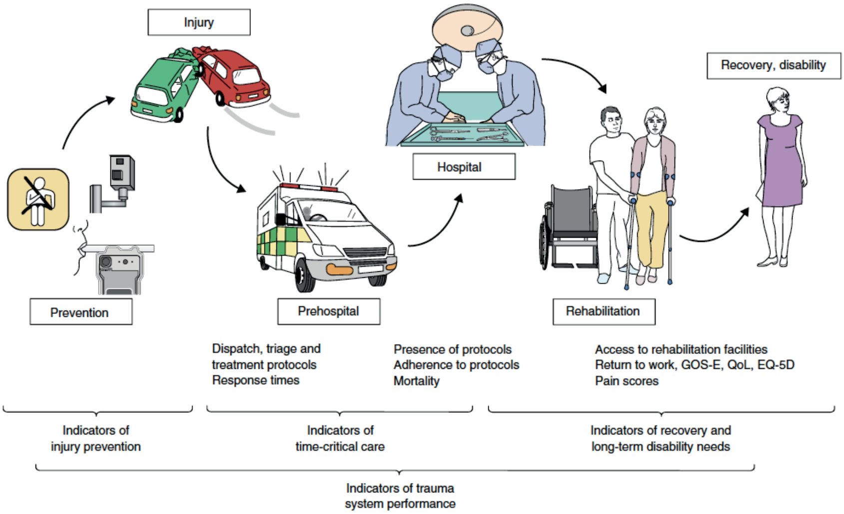

Figure 5: The continuum of care addressed by trauma systems reaches from prevention to patient outcomes.

Examples of trauma system performance measures are listed at the bottom. Reused from Gruen et al. (98) with permission from Oxford University Press.

Within the framework of trauma systems, there exist descriptions and requirements for structures and processes related to care provided by prehospital services, hospitals, and rehabilitation facilities. Also, strategies for injury prevention and a framework for quality improvement and control exist (66). Trauma registries serve as the backbone for benchmarking, research, and quality improvement work (67). Emphasis is put on pre-arranged coordination within a network of prehospital resources and hospitals, ensuring that patients receive resuscitation, transport, and hospital care that align with the severity of their injuries. This is typically implemented within a defined geographical area, forming a *regional trauma system* (66).

A trauma system built on the above principle, encompassing all injured patients within a region, is called an *inclusive* trauma system. This is now the recommended approach, as opposed to *exclusive* trauma systems that focus on only the most severely injured (66). Inclusive trauma systems aim to utilize all resources within an area to best care for all patients in a cost-effective manner, recognizing that very few hospitals can provide all resources and that most patients do not need extensive or highly specialized resources. In a modern sense of the term inclusive trauma care, also administrative, legislative, and economic factors are included (66).

The historic development of the trauma system model of care draws extensively on experiences from wars, industrial accidents, and motor vehicle incidents throughout the 20th century (99-102) This context is vital for this thesis, as today's trauma care model is built upon principles aimed at reducing preventable death and disability in a predominantly young population. This includes field triage tools and advances in the initial care of trauma patients (40, 103).

Trauma systems save lives and improve functional outcomes (4-6, 104). Studies also show effect of systematic trauma care for older patients: an adjusted odds ratio (OR) of 0.77 (95% confidence intervals [CI] 0.65-0.91) for mortality was observed in correlation with the maturing of a Norwegian trauma center's care (105).

When establishing trauma systems, they must be embedded in the overall healthcare system in place, taking into account available resources, population demographic, trauma epidemiology, geography, population density, and more (66, 106).

2.3.2 The Norwegian trauma system

In Norway, a plan for a national trauma system was first passed in 2007 and subsequently revised in 2016 (7, 107). Drawing inspiration from the trauma system models developed in the USA (66, 67), the Norwegian plan establishes uniform requirements for both prehospital and in-hospital services across the country (7). This comprehensive system is seamlessly integrated within Norway's broader healthcare system, structured around four regional health trusts. Each region encompasses one trauma center located at the region's leading university hospital, several acute care trauma hospitals, and a prehospital emergency medical services (EMS) system. Additionally, municipalities are responsible for out-of-hour clinics run by general practitioners. Hence, a diverse array of resources is readily available to uphold the aforementioned principle.

Norway had a total population of approximately 5.4 million people in the study period and a mean population density of 15 per km^2, although with large variation; approximately 80% of the population lives in urban areas, primarily along the coastline (Figure 6) (108). This variation in population density has implications for the organization of the trauma system, e.g., for air ambulance base and hospital localization.

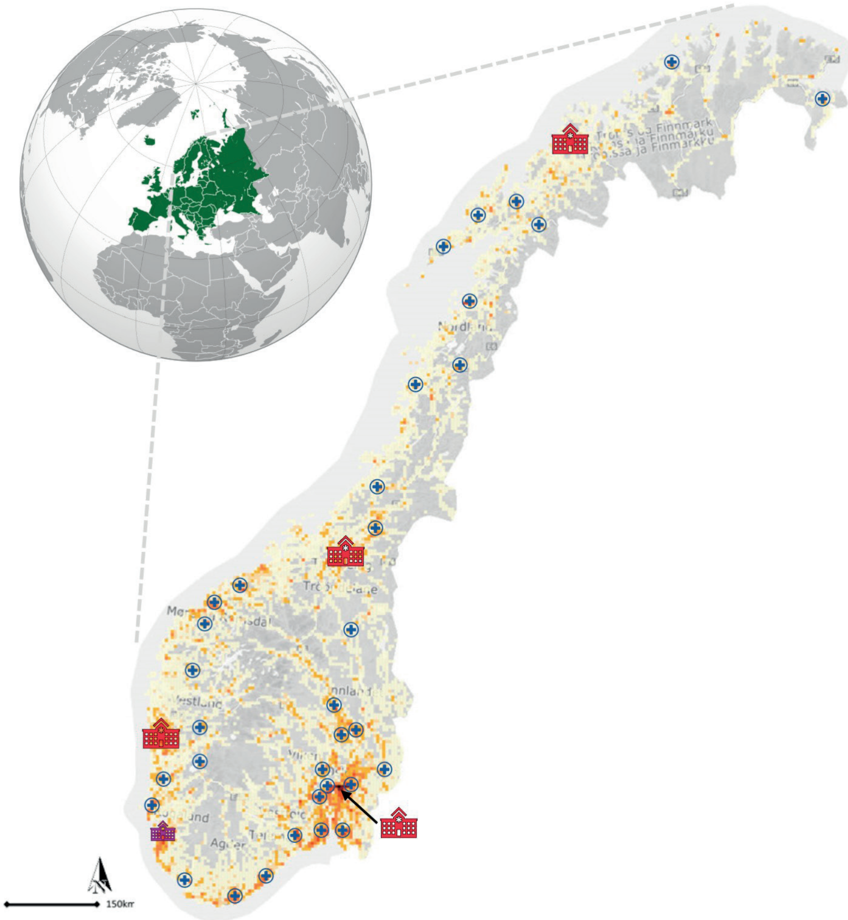

Figure 6: Overview of population density and location of trauma centers and acute care trauma hospitals in Norway.

Colors from light yellow to orange represent increasing population density. Neurotrauma centers are shown in red (regional trauma center) and violet (one acute care trauma hospital with neurotrauma services). Acute care trauma hospitals are shown in blue. Left: Norway's location in Europe. Reused from Cuevas-Østrem et al. (109) under the terms of the Creative Commons CC BY 4.0 license.

This thesis focuses on prehospital and initial in-hospital phases of care, and important features of these parts of the system are presented in relevant detail. Other parts of trauma care, such as injury prevention and rehabilitation, are outside the scope of the thesis.

2.3.2.1 Prehospital services

Prehospital services encompass EMCCs, ground, sea, and air EMS, and municipality-organized out-of-hours access to general practitioners (7). All are part of the government-run public health care system in Norway. Prehospital services' goals are early identification of patients with potentially severe injuries, providing guidance to bystanders/first responders in administering first aid, and dispatch of adequate resources with skills and training to initiate resuscitation and transport to the most appropriate care level according to the severity of the patient's injuries (66).

Calls made to the national emergency number (113) are evaluated by EMCC operators, typically specially trained nurses and emergency medical technicians (EMTs). The criteria-based system "Norwegian Index for Medical Emergencies" (Index) provides the EMCC operator with decision-making support and guides the dispatch of adequate resources (110). The 2018 version of the Index does not provide age-specific information to the operator, such as special guidance on trauma in older people. The national trauma field triage criteria (Appendix 1) are incorporated into the Index in a slightly modified version. Appendix 2 shows an example Index chapter pertaining to the assessment of injured people. Since the spring of 2020, video calls can be made to EMCCs (111).

Ground and sea-based EMS are mainly staffed by EMTs, paramedics, or nurses. The air ambulance services encompass rotor and fixed-wing aircraft. Helicopters are staffed with an anesthesiologist, a paramedic, and a pilot (112). Airplanes are primarily staffed with nurse anesthetists and anesthesiologists only when needed (112).

Helicopter EMS (HEMS) conducts the majority of primary missions in need of air ambulances in Norway (112). 14 ambulance helicopters, eight rescue helicopters, and ten fixed-wing aircraft are located across the country (2022) (113).

Doctor/paramedic teams, as in air ambulance crews, represent the most specialized part of the prehospital services. The teams are conducted by anesthesiologists and paramedics specially trained in advanced prehospital critical care. This includes point-of-care diagnostics and time-critical interventions such as point-of-care ultrasound, prehospital anesthesia, and advanced airway management (rapid sequence induction and endotracheal intubation), and chest drain insertion. Doctor/paramedic teams deploy by HEMS or rapid response vehicles (RRV) and most RRVs are co-located with HEMS bases and used by the crew for missions nearby and in no-flying conditions. RRVs have also been established as merely ground-based services with the same setup of personnel, training, equipment, and skill set.

The trauma plan gives pre-defined criteria for which level of care the patient should be transported to (*Paper II, Figure 1)* and criteria for interhospital transfer (7). The goal is to transport the patient to a facility able to provide definitive care directly from the scene. Exceptions occur when the patient's status is so severe that resuscitative procedures, i.e., damage control resuscitation (DCR) and surgery (DCS), are immediately required at a nearer acute care trauma hospital (7, 66).

2.3.2.2 In-hospital services

Hospital care is organized in a two-tiered system consisting of trauma centers (TCs) and acute care trauma hospitals (ACTHs). These correspond closely to level I/II and level III TCs, respectively, according to the American College of Surgeons Committee on Trauma (ACS-COT) criteria (or Major Trauma Centers and Trauma Units, respectively, according to UK terminology) (5, 66). Norway has four TCs, one in each regional health trust, which all are university-based teaching hospitals serving as the referral hospital in their region. The ACTHs are local hospitals across the country that have been given a designated role and responsibility to manage trauma patients according to the trauma plan.

During the study period, there were 38 ACTHs in Norway. Figure 6 shows the locations of all ACTHs and TCs in Norway.

Both TCs and ACTHs are required to have 24/7 trauma team availability, emergency general surgery, and critical care and high-dependency units (i.e., CCUs/HDUs, intensive care, and postoperative care units). They should provide DCR and DCS. TCs are additionally required to have all relevant clinical specialties available, advanced intensive care units, and to serve as lead hospitals regarding education and research in their region (7).

Patients with moderate-to-severe TBI receive 24/7 neurosurgical and neurocritical care services at all four regional referral trauma centers (TCs) and one ACTH (Stavanger University Hospital), jointly called neurotrauma centers (NTCs) in this thesis (Figure 6).

Interhospital transfer from ACTHs to TCs for patients requiring a higher treatment level is an important part of inclusive trauma systems. Criteria for considering interhospital transfer according to the national trauma plan, are listed in the trauma plan (7).

2.3.3 The Norwegian Trauma Registry

The NTR serves as the data source for three studies in this thesis and is therefore presented in detail. It is one of more than 50 national clinical quality registries whose purpose is to improve quality in Norwegian healthcare services and define and report on quality indicators.

2.3.3.1 Purpose, legislation, and ethics

The main purpose of the Norwegian Trauma Registry (NTR) is *"to contribute to improved quality in the treatment of trauma patients; reduce morbidity and mortality from trauma; ensure appropriate resource utilization and reduce unwarranted variation; preventive work"* (114). It is the main tool to fulfill important goals from the trauma plan regarding benchmarking, monitoring, reporting of quality indicators, and research in accordance with trauma system frameworks (7, 66, 67).

The NTR received status as a national clinical quality registry in 2006 and received the first national registrations in 2015 when an online registration platform was established (115). The NTR's status as a national clinical quality registry warrants mandatory data delivery from all trauma hospitals under the Regulations of Medical Quality Registries Act from 2019 (116). Patients are registered with a waiver of consent, but they receive written information about the registry and their access to withdraw information registered about them.

2.3.3.2 Registration of patients: Inclusion and exclusion criteria

The NTR collects information about patients meeting the inclusion and exclusion criteria listed in Table 2 (117).

Table 2: Inclusion and exclusion criteria for the Norwegian Trauma Registry

Inclusion	**Exclusion**
All patients admitted with the trauma team activated upon arrival at the emergency department of all acute care trauma hospitals and trauma centers in Norway, irrespective of ISS and NISS	Patients with chronic subdural hematoma without any other trauma-related injuries
All patients treated at an acute care trauma hospital or trauma center in Norway without activation of the trauma team, with one or more of the following injuries: • Penetrating injuries to the head, neck, torso, or extremities proximal to the elbow or knee • Head injuries with Abbreviated Injury Scale ≥3 • NISS >12	Patients with injuries from drowning, inhalation, hypothermia, and asphyxia (hanging, suffocation) without concomitant trauma

All patients who die at the scene of injury or during transportation to the hospital, and are not delivered to the hospital, but where prehospital management/treatment has been initiated.	Patients who die at the scene without the activation of prehospital resources

Abbreviations: ISS, Injury severity scale; NISS, New injury severity scale

The registrars are predominantly nurses and are employed at ACTHs and TCs. They identify and register information on eligible patients. Patients admitted without trauma team activation (TTA) are identified through hospital databases. The registrars are certified in accordance with the Association for the Advancement of Automotive Medicine to classify all injuries according to the AIS 2005, Update 2008 (37). Registrars also receive training in the registration procedures for the NTR and the registration manual (118).

2.3.3.3 Data in the registry

Information about patient status and management during prehospital, in-hospital, and rehabilitation phases is registered, in addition to demographic information and injury characteristics. The NTR registers data according to the Utstein template, a uniform minimal dataset to be recorded based on consensus among European trauma registries to allow for standardized reporting and comparisons (119). Additional variables are also recorded. All variables are coded according to the NTR registration manual (118).

Comorbidity is measured by preinjury American Society of Anesthesiologists physical status (ASA-PS) (120). The ASA-PS is a predictor of mortality (84).

2.3.3.4 Data quality

It is decisive that data in clinical quality registries are of high quality to serve as a platform for research and quality improvement (121). A commonly accepted definition of data quality in clinical registries is *"The totality of features and characteristics of a data set, that bear on its ability to satisfy the needs that result from the intended use of the data"* (122). Data quality is measured across six dimensions: completeness, correctness (validity), comparability, reliability, timeliness, and relevance, of which the two first are considered most important for data to serve their purpose (123). The data quality of the NTR is reported in annual reports.

Completeness refers to what degree all data that should be registered has been registered, and it is measured at the hospital level, patient level, and variable level. All TCs and ACTHs in Norway deliver data to the NTR. Of patients admitted with the trauma team activated, approximately 100% are registered (114). As increasing numbers of hospitals systematically identify patients not admitted by a trauma team (undertriaged patients), the total patient-level completeness is estimated at 90-95% (58, 114). The NTR reports that variable completeness is generally high (114).

Correctness (validity) refers to whether the registry reflects reality; is information registered about patients true – or valid? A validation study has been undertaken and is in publication process. Preliminary results reported in the 2021 annual report show that NTR data show excellent agreement with electronic patient records (124).

Comparability refers to the registry's ability to compare data across time periods, geography, and data sources. For example, changes to inclusion and exclusion criteria or core variables used in quality indicators or to identify study populations will have fundamental impact on interpretation of results. No such changes have occurred in the NTR during the time the studies in this thesis have been conducted.

Relevance and reliability: The NTR data collection is based on the Utstein template, which is an internationally recognized template for documenting and reporting data from trauma patients (119). This contributes to ensuring that relevant information is collected according to the purpose of the registry. It also contributes to reliability of data, as the Utstein template, together with a comprehensive registration manual written for the NTR, aims to ensure that all registrars have the same understanding of how to code data. All registrars are certified in both the NTR coding and AIS coding, regional coding support persons are available for discussions, and annual conferences are held for registrars to unify coding practice.

Data in the NTR relies on accurate registration in and subsequent reporting from patient records. Several data points are often captured on the same variable, e.g., blood pressure measurements. However, only a single time-point measure is allowed registered. Typically, this is the first measurement.

2.4 Clinical management of older trauma patients

2.4.1 Guidelines

Several guidelines provide instructions on the care of trauma patients. In the Norwegian trauma system, the Prehospital Trauma Life Support (125) and Advanced Trauma Life Support (126) curriculum form the basis of training for clinical personnel, as in several other countries. Regarding TBI management, Scandinavian head injury guidelines (127) and the Brain Trauma Foundation guidelines (128) form the basis for clinical management. None of these guidelines advocate a different – more passive – approach to older than younger trauma patients. To some extent, emphasis is put on avoiding pitfalls and recognizing the high risk of adverse outcomes in this population. The Norwegian field triage tool, for instance, suggests a lowered threshold for activating the trauma team and considering transfer to a TC in patients with age >60 years and/or comorbidity (Appendix 1).

All guidelines give poor guidance on when not to transfer patients to a higher level of care, which is particularly relevant for *Studies III and IV* (129).

2.4.2 Clinical management differences

Despite guidelines' general recommendations to not manage older trauma patients differently than younger adult patients, evidence shows that it commonly occurs. During this thesis' study period, the body of evidence showing differences in clinical management has grown beyond the literature that underpinned the rationale for this study.

Older adults are frequently undertriaged to highest-level trauma center care and trauma team admission (20, 22, 130-132). They are less likely to be transferred to trauma center care when first received at an acute care hospital (23, 69).

Further, an analysis of a large German cohort by Spering et al. indicated lower prehospital intubation rates and less volume replacement therapy, more restrictive whole-body CT scans, and lower intensive care utilization (75). The previously mentioned TARN report showed that initial management was more often led by more junior doctors (2).

For TBI patients, Skaansar et al. found a reduced treatment intensity for older adults, reflecting a composite measure of ICP monitor placement, ventilator treatment, and evacuation of intracranial mass lesions in a Norwegian neurotrauma center population (91). Another Norwegian study found lower transfer rates from acute care trauma hospitals to neurotrauma centers for older patients with moderate-to-severe TBI (133). The Lancet Neurology Commissions on TBI from 2017 and 2022 highlight the need for more research on how to best manage the growing population of older TBI patients (62, 134). Participants in this thesis' research group (the co-supervisors) had frequently experienced discussions in trauma courses about how challenging it could be to get TBI patients accepted for transfer to NTCs, particularly older patients. This aligned with some existing literature from the UK: Kirkman et al. showed reduced transfer rates for older patients with cerebral contusions, and a TARN report showed both reduced transfer rates, approximately 1.5 hours longer time to head CT in older patients with severe TBI (AIS ≥3), longer time to neurosurgery, and lower rates of neurosurgery (2, 24).

Poor triage tool sensitivity has been indicated as a contributing cause of undertriage. Systematic reviews have found poor sensitivity in detecting severely injured older people with trauma in general (135), and TBI specifically (136).

As this overview of management differences shows, there was a paucity in the literature about access to advanced prehospital care, i.e., doctor/paramedic teams, air ambulance transportation, and prehospital interventions. Furthermore, care pathways and factors influencing interhospital transfer to NTCs were poorly described.

2.5 Patient safety

Quality in healthcare rests on seven sub-dimensions, with patient safety, clinical efficiency, and people-centeredness being fundamental for achieving high-quality care (137, 138). In the Norwegian context, patient safety is defined by the Norwegian Directorate of Health as "*protection against unnecessary harm resulting from the services or lack of services provided by the healthcare services*" (my translation) (139). This definition aligns with international definitions and research, emphasizing the importance of reducing avoidable harm (137, 140-142).

Within the scope of this thesis falls the aspect of patient safety related to the unnecessary harm that may result from the *lack of services*. Drawing from experiences (See Introduction) and relevant international literature (Chapter 2.4.2), it is evident that the lack of proper access to trauma care for older people, contrary to established guidelines, poses a significant patient safety risk within modern trauma systems. Prior to this project, their status within the Norwegian trauma system was poorly studied.

To improve quality and patient safety, it must first be measured to know the current status. Quality indicators (QIs) contribute to the improvement of patient safety by allowing relevant, reliable, and valid measures related to the structure, process, or outcome of health services to be reviewed and acted upon (143, 144). Patient safety indicators in trauma care are frequently process indicators (145). They aim to reflect what is considered optimal treatment according to guidelines (7). National and international professional organizations (e.g., Norwegian National Advisory Unit on Trauma, ACS-COT, and WHO) advocate for measuring the quality and patient safety of trauma care using QIs (7, 66, 106). However, no internationally recognized set of quality indicators have been agreed upon, and a systematic review identified some 1500 QIs used in trauma care worldwide (146). Examples of quality indicators in trauma care are 30-day mortality rates, undertriage to trauma team rates, intubation rates in patients with GCS<9, and x-ray imaging rates upon admission.

A graphical overview of the interplay between trauma outcomes and QIs in trauma care is displayed in Figure 7.

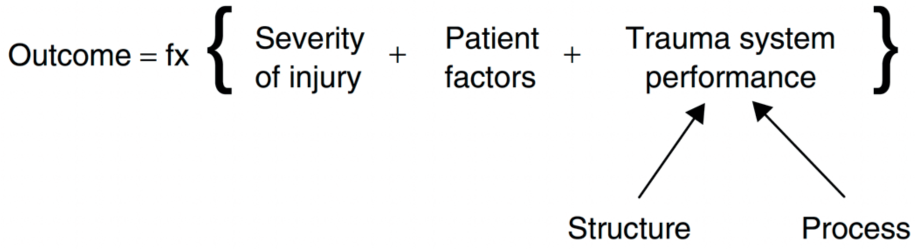

Figure 7: Relationship between the structure, process and outcome of healthcare.

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3 Thesis aims and objectives

The overall aim of this thesis was to assess the presence of patient safety challenges in the initial care of older trauma patients in Norway, and, if so, identify risk areas that require further investigation in future research.

The specific objectives of each study structured by study number were:

I. To describe the Norwegian geriatric trauma population by assessing differences in demographic and epidemiological characteristics between age groups, as well as describing injury characteristics, level of care, and outcomes with data from the NTR.
II. To compare prehospital and in-hospital clinical management of adult and older trauma patients, focusing on time-critical interventions and radiological examinations.
III. To describe characteristics and care pathways and identify factors associated with interhospital transfer to NTCs for patients with isolated moderate-to-severe TBI primarily admitted to non-neurosurgical ACTHs.
IV. To explore the decision-making process for transferring patients with isolated TBI from ACTHs to NTCs, elucidating factors influencing these decisions, and how involved surgeons weighed these factors.

4 Materials and methods

This chapter begins by providing the rationale behind and philosophical underpinnings of the selected study designs including the integration of quantitative and qualitative methods. Then follows a presentation of the quantitative, qualitative, and mixed methods used in the studies comprising this thesis.

4.1 Study design

This thesis comprises four studies: three quantitative and one qualitative. *Studies I-III* are retrospective cohort studies and *Study IV* is a focus group interview study. *Studies III and IV* focus on the same research questions and the results are mixed in this thesis, forming a convergent mixed methods design. Considering all studies in the thesis share the overarching aim to provide new information about patient safety risks for older trauma patients in Norway, the overall design is classified as mixed methods.

4.1.1 Philosophical underpinnings of study designs

Applying a combination of methods within the same research project is underpinned by a pragmatic epistemological position (147). Epistemology refers to theories of the nature of knowledge. Pragmatism provides a conceptual framework where research questions are allowed to determine the methods best suited to answer these questions (148).

Historically, some have argued that quantitative and qualitative methods apply incompatible paradigms (i.e., typically (post)positivism and constructivism). However, today this standpoint is rejected by most and mixed methods research has a sound theoretical framework and methodological literature (147, 149, 150). The positivist paradigm that underpins quantitative research assumes that an objective description of reality – one truth – is identifiable if unbiased observations are measured through appropriate scientific methods (151). The constructionist paradigm assumes that reality is constructed through all our interactions and experiences and that research must be understood as a product of how the researcher came to understand it (151). The pragmatic stand is to consider how the research question could best be answered without being locked to epistemological perspectives (147, 148).

4.1.2 The rationale behind selected study designs

In designing this project, our approach was to select the methods that were best suited to address the research questions, without being restricted by paradigms. Various methods possess distinct strengths and limitations, and these factors were guiding our choice of methods.

Studies I-III employ a retrospective cohort design, analyzing data from a national clinical quality registry (the NTR). Using registries offers significant advantages such as data availability, cost-effectiveness, the potential for large sample sizes, the possibility to identify and focus on small sub-populations (i.e., patients with isolated TBI), the ability to examine multiple outcomes and exposures, and the potential for long-term follow-up (50, 152). Furthermore, clinical quality registries typically identify a population with specific clinical characteristics and highly relevant information regarding this condition. However, certain inherent limitations associated with this design must be acknowledged, including reliance on information registered by others, potential concerns about data quality (122), constraints imposed by the variables available in the registry (e.g., leading to lack of information about potentially important confounders), the risk of selection bias, the risk of missing data, and the fact that only associations, not cause-and-effect relationships, can be established (50, 152).

Study IV employs an experiential qualitative design, which was chosen due to the exploratory nature of the study. Experiential qualitative research is driven by the aim to better understand people's own perspectives and practices, with a focus on presenting what is expressed in the data (151). Through a qualitative method, we could gather rich contextual data from interviews, explore the subject matter in-depth, comprehend the realities faced by participants, and gain richer insights into the decision-making process investigated in *study III* (151). We took into account the limitations associated with qualitative research. These included concerns about transferability, the time-intensive nature, and the challenges related to acquiring the necessary skills to demonstrate sound methodological practices, such as understanding the fundamentally different underpinning scientifical paradigm, in an otherwise predominantly quantitative project. Considering the aim to better understand the decision-making process regarding the interhospital transfer of TBI patients, it was deemed valuable to add a qualitative study. Such a study could bring forth different influencing factors and provide a more nuanced perspective.

The convergent parallel design was employed to mix results from *studies III and IV* (150). This refers to conducting quantitative and qualitative studies at concurrent timing, giving equal priority to both methods throughout the project, keeping the studies independent throughout the analysis phase, and integrating the results during collective interpretation. The integration phase will be this thesis (see Chapter 6.1.3). Drawing on the typology from Bryman, our reasons for mixing methods were completeness and offset, referring to a view that the methods combined can obtain a more comprehensive understanding of the topics of interest, and that combination of the methods offset their separate limitations and utilize the strengths of both (153).

4.2 Setting

The joint setting in this thesis is the Norwegian trauma system which is described in detail in Chapter 2.3.2. Specifically, the included studies concentrate on two key areas: prehospital and emergency department management (*Studies I and II*), and the intrahospital transfer of patients with isolated TBI (*Studies III and IV*). All 38 ACTHs and four TCs in Norway and their corresponding prehospital services, contributed data to these studies (Figure 2).

4.3 Quantitative methods

In this thesis, *Studies I-III* utilized quantitative methods to analyze data obtained from the NTR in observational study designs. These methods are described in this chapter in accordance with the STROBE statement (154).

4.3.1 Study population

In *Study I,* we included patients who were 16 years or older and had a NISS≥9. Patient registrations in the NTR were excluded if age or AIS were missing as these were instrumental in determining inclusion criteria. Moreover, patients without any detected injuries or those with injuries resulting from drowning, burns and inhalation, hypothermia, or asphyxia without concomitant trauma were excluded.

Study II applied the same inclusion criteria with the addition of a criteria that the patients had to be attended by a trauma team upon admission to the hospital. The aim was to target a population that was recognized as trauma patients during the clinical management subject to investigation. Exclusion criteria were identical.

The threshold of NISS≥9 was used in *Studies I and II* to define severe injuries with the following rationale: First, the NISS was preferred over the ISS because studies have found improved predictive capabilities of the NISS overall (36), and we could not find studies specifically comparing the NISS and ISS for defining trauma in an older population. However, we reasoned that given the high prevalence of head injuries, and the impact isolated body region injuries could have on older people because of their reduced physiological and anatomical reserves (such as the mortality and morbidity related to chest injuries (155)), the NISS was preferred over the ISS because of its calculation irrespective of body regions. Second, the threshold of ≥9 was chosen to account for older people's increased risk of poor outcomes even at lower injury severity measures than in conventional definitions. A study by Palmer et al. comparing different ISS and NISS thresholds using the same AIS version as in the NTR, found that approximately 25% of patients had died following injury despite having ISS and NISS under the examined thresholds of 12 and 15, respectively (34). Presumably, many of these patients were older, thus we set the threshold to NISS ≥9.

The reasoning for applying a threshold of age ≥65 has been given in Chapter 2.1.2.

In *Study III*, we aimed to identify patients with isolated moderate-to-severe TBI, i.e., absence of severe extracranial injuries. The following inclusion criteria were applied: 1) head injury with AIS scores of 3 to 6; 2) no extracranial AIS scores higher than 2; and 3) a maximum of one extracranial injury with an AIS score of 2.

We aimed to identify a population for whom the TBI would be a determining factor in considering transfer to NTCs. It is consistent with how previous studies have defined isolated moderate-to-severe TBI (156, 157) and the Norwegian trauma plan (7), which recommends transferring patients with injuries in three or more body regions to a TC. Moreover, this definition allowed for the inclusion of patients with extracranial injuries unlikely to affect transfer decisions or outcomes considerably. Some studies have applied narrower inclusion criteria, such as including only patients with no extracranial injuries at all. We discussed this approach in the research group and decided that it would lead to the exclusion of patients where the TBI indeed would be the cause of transfer discussions between ACTHs and NTCs, thus potentially introducing selection bias.

We also considered setting the inclusion criteria at AIS Head ≥4, which likely better represents patients where an indication for neurosurgical procedures would be present. However, we chose to include patients with AIS Head ≥3 because it largely reflects detectable intracranial pathology or cranial fractures on CT reflecting real-world management dilemmas. The study applied similar exclusion criteria as *Study I*, with the additional exclusion of patients with chronic subdural hematoma without concomitant trauma.

4.3.2 Data sources and variables

4.3.2.1 Data sources and sample size

Data for *Studies I-III* was obtained from the NTR. The sample size was arrived at by applying inclusion and exclusion criteria on the total number of registrations in the NTR between January 1, 2015, and December 31, 2018 (*Study I and II*) and between January 1, 2015, and December 31, 2020 (*Study III*). Formal sample size calculations were not performed because the outcomes of interest were already existing, which would make it analytically meaningless (158).

4.3.2.2 Variables

Variables used in *Studies I-III* followed the NTR definition catalog which corresponds to the Utstein template for uniform reporting of data from trauma registries (118, 119).

Some variables underwent recategorizing compared to their original Utstein template or NTR definitions, as shown in appendixes to the papers. This was primarily by merging categories in variables with many categories to increase the readability of tables and figures. An example is the merging of the in-hospital level of care variable score components "Critical care unit (CCU)" and "High dependency unit (HDU)" to "CCU/HDU".

Data cleansing was performed before analysis by summarizing and displaying the data. The goal was to identify incorrect or corrupt information to correct it (if possible) (159). For example, a negative age was observed in approximately five patients with otherwise good registrations. This was likely caused by a technical error somewhere in the registration or export process, and it was solved by contacting the registrar at the registering hospital for correct information.

As part of the data cleansing process, we examined the variables for outliers, which are data points that are unusual compared to the other variables (159). They may distort results and should be dealt with. Continuous variables, such as blood pressure measurements and time intervals, were displayed graphically (e.g., histograms). Through visual inspection and clinical expertise, we identified outliers. For instance, most patients had a median time from admission to chest X-ray imaging of approximately five minutes, but a few patients had much longer times. We considered imaging that occurred more than 90 minutes after admission as unlikely a part of the initial emergency management of the trauma patient but rather imaging that occurred later in the management process and deemed them outliers. These cases constituted 1.6% of all who underwent imaging.

A key part of the data handling was the operationalization of the NTR raw data. For instance, AIS codes were originally given as non-categorizable and non-searchable string variables. We developed a script to read each code and create new variables that allowed categorizations based on body regions and severity.

This was work intensive, but a prerequisite for important analyses in both *Study I and III.* Furthermore, transfer status was not clearly given by the NTR dataset, so stepwise quality control including admissions date and time, was assessed for all patients with multiple registrations.

Study I

For *Study I,* the following information was obtained from the NTR: Age, sex, preinjury ASA-PS, injury location, AIS, NISS, dominating injury type, mechanism of injury, the highest level of prehospital care, prehospital transportation mode, prehospital time, primary and secondary admission hospitals, trauma team activation, highest level of in-hospital care, discharge destination, and 30-day mortality.

Reporting of *outcome measures* followed the protocol (1): *demographic and epidemiological characteristics* included age, sex, preinjury ASA-PS, and injury location. Injury location was reported according to the Centrality Index of Norway (108) based on municipality number. *Injury characteristics* encompassed dominating injury type (blunt/penetrating), mechanism of injury, AIS, and NISS. *Management and level of care* encompassed prehospital time (time from alarm to hospital arrival), highest prehospital level of care (defined as physician, ambulance personnel, or other [including bystander first aid]), prehospital transport method, level of definitive care hospital (ACTH or TC), trauma team activation rate, and highest in-hospital level of care. *Patient outcomes* were reported as 30-day mortality and discharge destination.

Exposures were age and NISS.

Study II

For *Study II*, the following information was obtained from the NTR: Age, sex, preinjury ASA-PS, injury location, AIS, NISS, dominating injury type, mechanism of injury, prehospital GCS, SBP, and RR, the highest level of prehospital care, prehospital transportation mode, prehospital advanced airway management, prehospital chest decompression, prehospital time, level of the primary hospital (ACTH or TC), trauma team activation, ED GCS, SBP, and RR, ED intubation, ED chest drain, time from admission to X-ray chest and/or CT, ED X-ray chest and pelvis, ED CT imaging, and 30-day mortality.

Outcome measures were reported according to the protocol (1): *Time-critical interventions* encompassed prehospital advanced airway management (intubation and supraglottic devices), prehospital chest decompression (needle, incision, or chest drain), ED intubation, and ED chest drain insertion. *Radiological examination* encompassed an X-ray of the chest and/or pelvis, CT imaging (reported as any CT, not possible to differentiate between body region or full-body scan), and time intervals from admission to these investigations. *Prehospital management* included reporting the highest level of prehospital care, transport method, level of the primary hospital, and prehospital time, in addition to time-critical interventions.

Exposures were age and NISS and GCS as measures of injury severity.

Study III

In *Study III,* the following information was obtained from the NTR: Age, sex, preinjury ASA-PS, injury location, AIS, NISS, dominating injury type, mechanism of injury, prehospital and ED GCS, level of primary and secondary hospital, information about transfer, trauma team activation, highest level of in-hospital care, and 30-day mortality. The road distance between all ACTHs and corresponding NTC was calculated using www.openstreetmap.org (OpenStreetMap Foundation, Cambridge, United Kingdom).

Outcome measures were the characteristics of transferred and non-transferred patients (demographics, injury characteristics, management, and mortality), care pathways (primary admission rates to ACTHs and NTCs, transfer rates from ACTHs to NTCs, and definitive care rates at ACTHs and NTCs), and identification of factors associated with intrahospital transfer.

For the latter outcome measure, *exposures* were identified from experience and the literature and included age (continuous), sex, preinjury ASA-PS, year of incident, injury site's urban-rural classification (according to Centrality Index of Norway (108)), distance from ACTH to corresponding NTC (km, continuous), injury mechanism, GCS score on admission to ACTH (categorized according to HISS (160)), and NISS (continuous).

4.3.3 Statistical analysis

Analyses were performed using SPSS v.27 (IBM Corp., Armon, NY) and R Statistical Software (*Study III)* using the mgcv-package for the GAM development (161) (v.4.2.0; R Core Team, 2022).

4.3.3.1 Descriptive statistics

Descriptive statistics were applied in all the studies. Continuous data with a normal distribution were presented as means with standard deviations. Continuous data with a nonnormal distribution were presented as medians with interquartile ranges. Categorical data were reported as numbers and percentages.

In *Studies I and II*, *stratification* was used; the main groups we compared were adult patients (16-64 years) vs older patients (≥65 years). To provide more insightful comparisons, outcomes were also reported for age subgroups (65-74 years, 75-84 years, and ≥85 years) and injury severity subgroups (NISS 9-14, 15-24, and ≥25). Stratification is a useful tool in analytical epidemiology to examine the presence of confounding and interactions (50), although the way it was used in these studies was merely descriptive.

4.3.3.2 Analytical statistics

In *Studies I-III*, statistical tests were conducted to test the null hypothesis of no differences between the groups, using the methods described above. For continuous data, means were compared using the independent samples t-test and the unequal variances t-test, while medians were compared using the Mann-Whitney *U* test. For categorical data, differences between groups were tested with Pearson's chi-squared test or Fisher's exact test. Effect size estimates were given as OR with 95% CI. A *P* value <0.05 (two-tailed) was considered to indicate significance.

These tests compared adult vs older patients (*Studies I and II)* and transferred vs nontransferred patients (*Study III)*. In *Study II*, the results of these comparisons were reported as odds ratios from the chi-squared tests to provide effect size estimates which carry more information than *P* values alone. This yields similar results as univariate logistic regression analysis.

In *study I,* we conducted a sensitivity analysis and in *study II*, we conducted a comparison not described in the protocol. These should have been acknowledged in the study reporting as *post hoc* analyses.

In *Study III*, a multivariable model was developed to identify the factors associated with interhospital transfer from ACTHs to NTCs. Multivariable models allow for adjustment of confounding factors, and assessment of effect modification, and are an efficient way to summarize the effects of several predictor variables (50). Confounding refers to a situation in which *"a noncausal association between a given exposure and an outcome is observed as a result of the influence of a third variable (or group of variables)"* (50). Interactions reflect that the effects variables have on each other are not constant across all levels of the other variable (50).

The generalized additive model (GAM) was chosen as the preferred multivariable model approach. The advantage of a GAM over an ordinary logistic regression model is that it can include nonlinear terms, and as age and NISS were determined non-linear, the GAM was chosen. We used the purposeful selection modeling strategy to build the model (162). This procedure tests all relevant variables in univariable analysis for statistical significance before entering them into the multivariable model, and tests for interaction terms and nonlinear terms and adds them if needed. Predictor variables tested are listed in Chapter 4.3.2.2. Estimates for the regression coefficients were presented as ORs with 95% CIs, and the effective degrees of freedom (edf) were given for nonlinear terms. The results from the GAM were presented as a table and as contour plots.

4.4 Qualitative methods

Study IV applied a qualitative focus group interview method, which is described in this chapter in accordance with the COREQ guidelines (163).

4.4.1 Researcher reflexivity

Researcher reflexivity is a key part of qualitative research because it recognizes the inherently subjective nature of the qualitative research process (164). Acknowledging that the researchers' experiences and preconceptions inevitably influence the research, it becomes crucial to consider them rather than neglect them (151). Subjectivity is not considered a problem as long as reflexivity is demonstrated. Reflexivity entails engaging in critical reflection on both the research process itself and the role of researcher (164).

Throughout the entire research project, careful consideration was given to the subjectivity of the researchers. As the lead researcher, my personal experiences with the subject matter, as previously discussed in the Introduction, have likely influenced various aspects of the project, including how I framed questions, analyzed data, and interpreted findings. It was essential to recognize the impact of these personal experiences, alongside my education, training, and involvement in elderly care. To ensure a reflexive approach, awareness of these subjects was emphasized, the topic was discussed with supervisors, and a research diary where thoughts and preconceptions were noted, was kept and used during the analysis stage. Also, reflexive notes were taken, the interview guide was collaboratively designed by a diverse team with broad perspectives, and all interviews were conducted by a team of two researchers.

Another example of our reflexive positions can be observed in how we, as interviewers (MCØ and EJ), navigated different ‘insider’ and ‘outsider’ positions during the interviews (151). We were transparent about our credentials and backgrounds with the participants. ‘Insider’ positions were positions we shared with the participants, such as we were all healthcare personnel with experience in emergency medicine. Both male and female perspectives were represented, mirroring the compositions of most groups. As a doctor, I shared a specific background with the participants. Concurrently, none of us worked in their specific field directly, making us outsiders to their work situation. The participants, on the other hand, shared work-related information about themselves. Transparency about this information contributed to establishing rapport and trust and shaped the nature of the conversations. This was considered during analysis.

4.4.2 Study design and participant selection

We chose to conduct a focus group study using inductive thematic analysis. Focus groups have the potential to bring forth a wide range of perspectives and viewpoints because participants draw on each other’s experiences through discussion (151). An inductive thematic analysis approach was chosen because we wanted to explore factors associated with transfer as emphasized by practitioners in the real world, not by existing theory.

A purposive sampling strategy was used for this study to recruit participants with potentially differing views (151). Therefore, we invited participants from hospitals with different sizes, distances to their corresponding NTC, and from different regions, and hoped to get participants with different sexes and years of experience. This was achieved. Invitations were sent from the lead researcher (MCØ) to key personnel in each hospital who were identified from the research group's network and contacted to serve as 'door openers'. Of the four key persons, one was a surgeon who met eligibility criteria and was thus a colleague of potential candidates, and three were academic leads in their departments. They forwarded the e-mail invitation to all potential candidates at their hospital with information about the purpose of the study and eligibility criteria for participation. Eligibility criteria were:

A) surgical residents or attendings at ACTHs with more than one year of experience as trauma team leaders, responsible for on-call conferences with their corresponding NTC.

B) neurosurgical residents or attendings at NTCs responsible for answering on-call consultations from ACTHs about interhospital transfer and subsequent neurosurgical management.

Four focus groups with four to eight participants in each group were decided as a reasonable starting point to get rich and informative data. Further evaluation of the sample size was planned thereafter. To capture potentially different perspectives and experiences, sampling was conducted from two regional health trusts. Participants from two hospitals within the same regional health trust were recruited to get information from collaborating hospitals (one ACTH and their corresponding NTC). The two ACTHs we recruited surgeons from were both small-to-medium-sized. The transfer distance by ground ambulance between these ACTHs and their corresponding NTCs was <100 km (drive time 30-90 minutes) for one hospital and >300 km (drive time >240 minutes) for the other.

4.4.3 Data collection

4.4.3.1 Interview guide

The interview guide was developed in collaboration with the whole research group which included experts in neurosurgery, general and orthopedic surgery, anesthesiology, trauma system development, and qualitative methods. Additionally, it was informed by current literature on the topic. The questions in the guide were framed as open-ended to elicit participants' perspectives and experiences. The guide covered topics such as current practices of on-call conferences, the factors considered in making transfer decisions and the influence of these factors on the decision-making process, and situations involving uncertainty and disagreement (Appendix to *Paper IV*). The interview guide was pilot tested on a registrar in orthopedic surgery who met eligibility criteria but from a non-participating hospital. Adjustments were made to the guide based on the feedback provided.

4.4.3.2 Interviews

Between April 2020 and June 2021, during the COVID-19 pandemic, four focus group interviews were conducted. Each focus group consisted of three to five participants. Our goal was to recruit four to eight participants in each group, as this range has been suggested to yield rich results (151). We did experience that the groups including four to five participants created the best group dynamic and discussions, compared to two groups with three participants. However, it did not necessarily produce richer content and was arguably more difficult to lead.

One interview was conducted via video communication and the rest in-person. All were audio recorded. To ensure consistency and familiarity with the subject matter, the interviews were conducted by the same two researchers (MCØ and EJ). The interviews began by clarifying the goal of gaining a deeper understanding of the processes involved in interhospital transfer of TBI patients. We wanted to avoid being seen as external reviewers of current practice. Field notes and initial reflections were written down after each interview and incorporated into the analysis (151). The interviews took place during regular working hours at the participants' hospitals without the presence of heads of departments or academic leads to encourage open and uninhibited discussions (151, 165).

The decision to terminate the data collection phase with four preplanned interviews was made after careful consideration of the data from the four interviews. We found that information about factors influencing the transfer decision was reoccurring in all focus groups, and although four focus group interviews were insufficient to declare true saturation, we deemed that we had collected rich material about core factors (166). In addition, the pandemic situation made access to hospitals challenging, and there were time limitations imposed by the funding constraints.

4.4.4 Data processing

Audio transcripts of each interview, lasting approximately one hour each, were transcribed verbatim. Three were transcribed by professional transcription services due to its time-consuming nature, and one by MCØ. During the transcript process, all participants' names were given pseudonyms. Data necessary to reidentify individuals were stored at a separate encrypted location, as were audio recordings and transcripts.

4.4.5 Analysis

Transcripts from the four focus group interviews were analyzed using Thematic Analysis (167). This method comes without requirements to specific theoretical positions and methods of data collection, can be applied to a wide range of settings, and is considered a good introductory method to qualitative methods (151). It is, however, criticized for its flexibility, which some have argued may lead to inconsistency when identifying themes (168). During the analysis, checklists for good thematic analysis (167) and reporting of qualitative research (163, 169) were used to increase trustworthiness and transparency (168).

Braun and Clarke present four steps of doing Thematic Analysis, which we followed iteratively (151): 1) Familiarization; 2) Coding; 3) Identifying and reviewing themes; 4) Defining and naming themes.

After familiarizing myself with the data by reading and listening to the interviews, initial coding was performed by one researcher (MCØ) in an inductive, 'bottom-up' way. An effort was made to be thorough and inclusive when evaluating the data to avoid giving too much attention to some striking quotes, particular interviews or findings that confirmed my preconceptions. Several candidate codes clustered around similar concepts, which made the basis for discussion between MCØ and EJ about a second coding structure. All interviews were then recoded accordingly. MCØ and EJ then discussed candidate themes. Finally, all authors were involved in defining and naming themes. nVivo 12 (QSR International) was used in the coding process.

4.5 Mixing methods

The convergent parallel design requires integration – mixing – of results from one quantitative and one qualitative studies into an overall interpretation (150). The integration face occurs after both studies are analyzed separately. The results from each study should be compared directly and the researcher is supposed to interpret results by discussing convergence, divergence, and relationships between the results, and how the studies combined may have created a better understanding of the topic (150).

4.6 Ethics

4.6.1 Ethical approvals

Approval for *Study I-III* was given by the Data Protection Officer of Oslo University Hospital, which is responsible for the Norwegian Trauma Registry (ref. no. 19/16593). According to Norwegian legislation, approval from an ethics committee is not required for studies of deidentified registry data for health services research (170). Deidentified data means that no directly patient-related personal information is given, such as social and security numbers, birth dates or names. There is, however, a risk of re-identification from deidentified registry data and publicly available information. To minimize this risk, we applied for as few variables as necessary and ensured encrypted access to data.

Approval for *Study IV* was given by the Norwegian Center for Research Data (ref. no. 141435).

4.7 Financial support

Research funding, grants, and support from industry may introduce obligations and ties with impact on the research. Independence is a precondition for credibility, but nonetheless, research must be funded. Thus, transparency is decisive for trustworthy results.

This project was funded in full by The Norwegian Air Ambulance Foundation, a non-profit non-governmental organization with the goal of promoting advanced prehospital emergency medicine. The funder had no role in designing the studies or the collection, analysis, interpretation, or drawing of conclusions from these studies.

5 Summary of results

5.1 Study I

We investigated the epidemiology and clinical management of older trauma patients (G2, age ≥65 years) in Norway, comparing their characteristics with adult patients (G1, age 16-64 years) in terms of demographics, injuries, management, and outcomes. A sample of 11,403 severely injured patients (NISS ≥9) was drawn from the Norwegian Trauma Registry. Older patients constituted 33% of the study population, which was higher than their proportion in the general adult population of Norway (17%). The older population had a higher proportion of females, more comorbidities, and were more frequently injured by blunt trauma, predominantly low-energy falls (40%). A severe head injury (AIS ≥3) was observed in 36% of all older patients.

Prehospital management of older patients showed lower utilization of air ambulances (All NISS subgroups: $P<0.01$; e.g., NISS 15-24: G1: 24% vs. 14%, $P<0.01$) and physician-led care (All NISS subgroups: $P<0.01$; e.g., NISS 15-24: G1: 30% vs. G2: 18%, $P<0.01$) across all injury severity levels. Prehospital times were longer for older patients with NISS <25 ($P<0.01$), and not different for patients with NISS ≥25. In-hospital management showed a lower trauma team activation rate overall (G1: 89% vs. G2: 73%, $P<0.01$) and across age and NISS subgroups. The difference in trauma team activation rate remained significant and substantial in a sensitivity analysis where patients with highest age and/or substantial comorbidity were excluded. A lower CCU/HDU admission rate was observed (All NISS subgroups: $P<0.01$, e.g., NISS 15-24: G1: 80% vs. 75%, $P<0.01$). Discharge to nursing homes was observed more frequently for older patients. Crude 30-day mortality rates were higher (G1: 2.9% vs. G2: 13.6%, $P<0.01$), which in the sensitivity analysis remained significant only for the most severely injured patients (NISS 15-24: G1 0.7% vs. G2 1.4%, $P=0.12$; NISS ≥25: G1: 10.3% vs. G2: 20.1%, $P<0.01$). This is the first comprehensive and nationwide investigation of the epidemiology of the older trauma population in Norway. Importantly, in the general trauma population in Norway, older people have different characteristics and receive a lower level of care than their adult counterparts.

5.2 Study II

We investigated the prehospital and emergency department clinical management of trauma patients, focusing on differences in time-critical interventions and radiological examinations between older and adult trauma patients (G1: 16-64 years, G2: ≥65 years). A sample of 9543 severely injured patients (NISS ≥9) attended by a trauma team upon admission were identified through the NTR to ensure identification of a population recognized as trauma patients during emergency care provision. Older patients were more frequently severely injured (NISS ≥15: G1: 51% vs. G2: 59%, P<0.001) and presenting with reduced consciousness (prehospital GCS score ≤13: G1: 20% vs. G2: 25%, P<0.001).

Older people were less frequently attended by doctor/paramedic teams (G1: 32% vs. G2: 23%, OR 0.64 [95% CI 0.57-0.71]) and transported with air ambulance to the primary hospital (G1: 24% vs. G2: 17%, OR 0.65 [0.58-0.73]). This difference was significant also in subgroups of patients with GCS<9 and NISS ≥15. Prehospital advanced airway management (AAM) and chest decompression (CD) occurred significantly less frequent among older patients with NISS ≥25 and GCS <9 (AAM only), but were not different at lower NISSs (GCS<9 AAM: G1: 53% vs. 41%, OR 0.61 [0.45-0.83]; NISS≥25: AAM: G1: 22% vs. 14%, OR 0.60 [0.47-0.76]; CD: G1: 3.9% vs. 1.8%, OR 0.46 [0.25-0.85]). In a *post hoc* analysis of the subgroup of patients attended by prehospital doctor/paramedic teams, no significant differences were observed regarding time-critical interventions, both overall and in the subgroups of GCS<9 and NISS≥25. In the ED, AAM and CD rates were lower for older patients with NISS ≥25, but not different at lower NISSs or GCS<9 (AAM only). Chest and pelvic x-rays were less frequently performed for older patients with NISS ≥25, but not at lower NISSs. Time to x-ray and computed tomography (CT) investigations showed statistically significant but clinically irrelevant differences between age groups and across injury severity strata (e.g., time to chest x-ray, NISS ≥25: G1: 6.4 min vs. G2: 7.5 min, P=0.006). The results show that despite similar injury severity, older patients received a lower utilization of advanced prehospital care and less prehospital and in-hospital time-critical interventions and imaging in patients with very severe injuries. Dispatch decisions have important consequences for the further treatment course.

5.3 Study III

We investigated characteristics and care pathways for patients with isolated moderate-to-severe TBI who were admitted to non-neurosurgical ACTHs and which factors were associated with interhospital transfer to NTCs. A sample of 1735 patients from all ACTHs and NTCs in Norway between 2015 and 2020 were included. Patients who were 65 years and older were more frequently admitted to ACTHs as the primary hospital compared to younger patients. Forty percent of the population underwent interhospital transfer to an NTC. Transferred patients were younger (median 60 vs. 72 years, $P<0.001$), more often male (75% vs. 63%, $P<0.001$), had less comorbidity (preinjury ASA-PS ≥3: 26% vs. 29%, $P=0.015$), were more severely injured (median NISS 29 vs. 17, $P<0.001$), and had lower admission GCS scores (≤13: 55% vs. 27%, $P<0.001$) compared to nontransferred patients.

To identify factors associated with interhospital transfer, a generalized additive model was developed, which showed that an increased transfer probability was significantly associated with reduced GCS scores, increasing NISS (until the effect was inverted at higher scores), and comorbidity in patients younger than 77 years. Factors associated with a decreased transfer probability were increasing age and comorbidity, and increasing distance between the ACTH and the NTC (except for extreme NISSs). Factors not associated with transfer were sex, mechanism of injury, or the centrality of the geographical injury site. The study used a novel and more advanced approach than previous studies to account for non-linear associations. The results quantified the impact clinical features such as age and comorbidity and system-factors such as transfer distance had on transfer probability. It also identified how measures of injury severity that are available in the ED (GCS and NISS as a surrogate measure of CT results) influenced the transfer decision. Furthermore, the results demonstrated that ACTHs managed a substantial burden of isolated moderate-to-severe TBI patients primarily and definitively, highlighting the importance of high-quality neurotrauma care in non-neurosurgical hospitals.

5.4 **Study IV**

In this qualitative study, we explored the decision-making process leading to transfer decisions for patients with isolated TBI. We wanted to increase the knowledge about factors influencing the decision to better understand what determined older patients' access to specialized neurotrauma care. Thematic analysis of interviews identified one overarching theme and six main themes. The overarching theme was: 'The chance of a favorable outcome', which reflected how participants were constantly considering various factors' influence on outcomes and thus on the transfer decision. The main themes were: (A) 'Establish TBI severity: Glasgow Coma Scale score and head CT', (B) 'Preinjury health status: comorbidity, functioning, and age', (C) 'Distance from ACTH to NTC: distance is time and time is brain', (D) 'Uncertainty and insecurity', (E) 'Capacity at NTC', and (F) 'Next of kin involvement'. These themes captured clinical and system-level factors and reflect a dynamic and multifaceted approach to making transfer decisions. The themes were interrelated, meaning that the decision could be influenced by several factors with an influence on each other's impact. The effect of factors in theme (B), preinjury health status, showed a dose-response effect on reduced transfer likelihood.

The findings indicate that involved clinicians emphasize the importance of making patient-centered decisions. They consider individual patients' risk factors and chances of a favorable outcome.

6 Discussion

6.1 Discussion of main findings

The aim of this thesis was to assess whether patient safety challenges existed in the initial care of older trauma patients in the Norwegian trauma system. We identified challenges, particularly in the prehospital phase and regarding care pathways of older TBI patients, but also strengths of the current system.

We found that older trauma patients received less advanced prehospital care despite equal injury severity, were less often met by a trauma team upon hospital admission, and received a lower level of in-hospital care, demonstrated in part by lower trauma center admission rates. The crude 30-day mortality rates were higher, and older patients were more frequently discharged to a nursing home. Older trauma patients constituted 1/3 of the total adult trauma population and exhibited distinct demographic and injury characteristics; they were more often female, had more comorbidity, and were predominantly injured by low-energy falls.

Severe head injuries were observed in more than every third of older trauma patients, a condition associated with poor outcomes (91, 171). Older patients underwent prehospital intubation less frequently despite GCS scores <9. We found that older patients with isolated moderate-to-severe TBI were more frequently admitted to non-neurosurgical hospitals as the primary hospital compared to younger patients. We also showed a reduced probability for interhospital transfer to NTCs; advanced age and comorbidity were associated with a reduced transfer probability, and qualitative analyses also identified preinjury functional impairments as an important factor influencing the transfer decision. Furthermore, we showed that the transfer decision was prone to communication errors.

Importantly, we also identified areas where care was more similar. This was perceived as strengths of the current system. In the initial in-hospital management, the primary survey, differences in radiological imaging rates and time from admission to imaging did not exist or were clinically negligible. Furthermore, TBI patients were identified for interhospital transfer based on a broad, patient-centered assessment of individual patients' health status.

Several of the findings in this thesis confirm findings from other studies. Undertriage rates found in this thesis correspond with findings from others (135). Increased risk of definitive care ACTHs confirms findings from the UK (172), and the higher frequency of discharge to nursing homes and higher mortality rates are as expected and align with other studies (2, 47). Unsurprisingly, given that trauma systems internationally share structural similarities and use the same international guidelines.

However, this thesis adds to current knowledge about how older trauma patients are managed differently than younger adults; to our knowledge this thesis is the first to show that older patients have a reduced availability of doctor/paramedic team management, the most advanced prehospital resource, in a national population. And consequently, fewer prehospital advanced interventions were performed.

The studies about interhospital transfer of TBI patients take a novel look on an old problem; the TBI patients not directly admitted to NTCs. Most previous studies have only identified those secondarily transferred to an NTC from institutional NTC registries, leaving knowledge about the non-transferred population behind. Thus, a national population-based comprehensive investigation of patients with isolated TBI admitted to non-neurosurgical hospitals was new. Furthermore, we deemed it necessary to use more sophisticated methods than previous studies had, to account for non-linear and interacting factors influencing transfer.

The Scandinavian countries share some characteristics that make it interesting to find these management differences also here, such as public health care, little violence, and a quite homogeneous population. Hence, socioeconomically driven information biases are likely lower than in a US setting. We believe that this strengthens the conclusion from elsewhere that providing care to older trauma patients is an inherent weakness in current trauma system designs.

The undertakings of this thesis draw on the strengths and importance of having a national trauma registry to monitor care. It allowed a comprehensive investigation across both prehospital and in-hospital management and across several outcome and process measures. In total, it provided a quite unique overview of the limitations a national trauma system currently faces in providing care for older patients.

6.1.1 Prehospital patient safety challenges

I want to emphasize the importance of differences observed in prehospital management. For the purposes of this discussion, I include the primary admission hospital level and trauma team activation in the prehospital phase. Because they are highly dependent on decisions made by prehospital personnel based on their situational assessment. Lack of access to recommended care may impact outcomes and are considered potential patient safety risks (Figure 7) (139). This risk likely increases when multiple risks coincide, such as for severely injured older patients who are not attended by a doctor/paramedic team, are not receiving advanced interventions (e.g., intubation and blood products), are transported to an ACTH instead of a TC, and are not admitted with a trauma team activated.

Trauma in the older patient should be added to the list of great imitators in medicine; diagnoses that present with nonspecific symptoms and may mimic several other conditions. For all the reasons listed in Chapter 2.2.4, recognizing trauma in this population can be difficult, and this is at the heart of the prehospital patient safety challenges observed in this thesis and other publications. The clinical presentation may be non-alarming or mimicking other diseases until a sudden deterioration unmasks the severity. In the words of dr. Platts-Mills: *"But when the case is reviewed to determine the triage error, there is no smoking gun."* (173). We found that across all assessed checkpoints on the timeline from injury to trauma team admission, the management of older patients were at significantly lower rates. As these observed differences occur in the phase where the patient is largely undiagnosed, we believe they reflect unintentional system-imposed restrictions to care, rather than being the result of well-considered treatment limiting decisions. They are perhaps consequential errors, and the first point of entry is the EMCC.

The core tools to guide decision-making in this phase are the Index by EMCCs and the field triage tool by prehospital personnel. Whereas field triage tools have been scrutinized for performance and potential improvement (135, 136, 174), the Index and the role of EMCCs have not. The EMCCs lead the dispatch of the initial response, including prehospital doctor/paramedic teams, and communicate early findings. The Index version from the years of this study did not inform the operator adequately on the particularities of older trauma (Appendix 2). Other conditions that may be difficult to recognize have arguably received more focus in recent years, such as sepsis and stroke, which may have reduced the awareness of “atypical trauma”. The lack of a smoking gun, i.e., clear indices that something is off, shows itself in that an upgrade of severity after the arrival of paramedics, is much more common in older patients in general (175) and for older trauma patients attended by HEMS (176). I have been fortunate enough to be invited to cooperate with colleagues from the National Centre of Emergency Primary Health Care on an ongoing revision of the Index. Hopefully, this, together with video calls, is a start on the road to improvement.

After EMS arrive, they make their own assessments. The triage tool provided by the trauma system to guide them in recognizing potentially severely injured trauma patients, transport destination, and whether trauma team activation is indicated upon admission, has limitations (Chapter 2.4.2). Again, this relates to the atypical clinical presentation. This likely explain the high undertriage-rates to some extent. However, one study from Norway, and one study from Australia found that when investigating undertriaged patients, most had vital signs or other findings that would give a hit in the triage tool (177, 178). Furthermore, both studies concluded that the real undertriage rate was actually within the <5% advocated by the ACS-COT. Caterino et el. implemented age-specific triage criteria for older patients in a statewide trauma system (179). The sensitivity increased, but regardless, transport rates to trauma centers remained unchanged. They concluded that non-compliance was likely the problem, and focus should be increased on implementation. In my opinion, these findings may reflect a mix of reasons. Poor knowledge, little training, and even well-considered treatment-limiting decisions could influence the results. Caution should therefore be exercised in judging undertriage rates.

To receive an advanced intervention, prehospital doctor/paramedic teams were a prerequisite; thus our findings of lower doctor/paramedic team attendance rates and lower intervention rates go hand in hand. It is worth noting that the results from the *post hoc* analysis from *Study II* (*Paper II, Table III*) warrant some consideration. We found that if an older patient was attended by a doctor/paramedic team, they received similar intervention rates as younger patients. Whether this was because they were a carefully selected population or reflected that as long as they were attended, they received necessary interventions is not clear. It may reflect an unmet need for advanced interventions by unattended older patients and should therefore be a focus for future research.

6.1.2 In-hospital patient safety challenges

The in-hospital management assessed in this thesis did not show the same pattern of differences as in the prehospital phase. The important caveat is that *Study II* only included patients attended by a trauma team, as a marker associated with an increased likelihood of being considered a trauma patient during the prehospital clinical management. It is still an important finding that trauma teams made no clinically significant difference in the primary survey of young and old adults, in line with the intention of being a quick way to clarify the extent of injury. The lower rates of advanced interventions in the ED for older patients with NISS $\geq$25 could thus be understood as well-considered individual decisions.

The fact that we found less alarming patient safety challenges in the in-hospital phase, does not acquit older trauma patients' in-hospital care of patient safety challenges in Norway. High complication rates, including delirium, longer length of stay, and readmissions have been pointed out by other studies (76, 180). These were not available for us to report from the NTR. Adopting successful interventions from elsewhere should be considered by Norwegian hospitals. Implementation of care pathways, including such as comprehensive geriatric assessments, multidisciplinary assessments (e.g., by nurses, physiotherapists, and pharmacists), and predefined order sets to predefined high-risk patient populations, has shown improved outcomes such as reduced mortality and delirium rates (180, 181).

6.1.3 Interhospital transfer of patients with isolated TBI: mixing results and patient safety considerations

The care pathways of patients with moderate-to-severe isolated TBI in Norway showed similarity to other studies: approximately 50% of these patients were primarily admitted to ACTHs in our study, corresponding well with 60% from an English study (182), and 52% from a US study (183).

Most previous studies have, however, been restricted to patients admitted to NTCs. This limits the basis of comparison of factors associated with transfer but increases the novelty and the importance of our undertakings. One comparable study also identified an increased risk of primary admissions to ACTHs and reduced transfer probability with increasing age and comorbidity (133). The quantitative study *(Study III)* is unique because the application of more advanced statistical methods allowed for quantification of the influence of various factors in a way that accounts for the non-linear association and interacting terms. The results from the quantitative study were sensible from a clinical perspective. Unfortunately, they were limited by the lack of adjustment from factors suggested by literature to inform the transfer decision, such as antithrombotic medication and frailty, unavailable from the NTR. Importantly, the study highlighted the need for a better understanding of underlying factors. That was achieved by the qualitative study *(Srudy IV)*.

Combined, the results from *Studies III and IV* showed both convergence and divergence. Both studies emphasized the importance of injury severity (both reduced GCS scores and increased NISSs) for increased transfer probabilities, yet not too severe. The quantitative data showed an inverted U shape which overlapped very well with a quote from one neurosurgeon: "*It ultimately comes down to whether the injury is too mild or too severe" (Paper IV)*.

Age's impact on transfer was a central matter in the quantitative study. It showed that with advancing age, the transfer probability dropped; with age >85-90 years, transfer probability never exceeded 30%. This was nuanced in the qualitative study, where age was said to be clearly secondary to comorbidity and functional impairments, at least to an age threshold of 85. This is an interesting observation from the qualitative study, because the age of 80-85 years is where the transfer probability really starts to drop in the quantitative studies.

The results on comorbidity were also highly convergent: In the quantitative study, preinjury ASA-PS score was the measure of physical status and comorbidity, and it was associated with reduced transfer in older patients. In the qualitative study, comorbidity was addressed by the participants in a broad manner, not disease-specific, with a focus on capturing the burden of comorbidity on their physical status. It resembles what is captured by ASA (184). Again, the qualitative study brought nuance to similar results: Closely related to the importance of comorbidity was the importance of functional impairments, both due to their relationship to risk of surgery and ability to benefit from rehabilitation. This underscores a limitation with the quantitative study; ASA is not a measure of functional impairments, suggesting that future studies should include broader measures of comorbidity, e.g., frailty (77, 185).

In the qualitative study, ethical perspectives were present in all the group interviews. Quotes like *"Can they withstand an operation, and if so, if one operates on them, what do you save them back to?" (Paper IV)* are representative of their considerations. It is a strength of the qualitative work that it captured what the registry studies could does not.

Studies III and IV show some strengths in how patients with isolated moderate-to-severe TBI were selected for specialized care that are worth dwelling over. Contrary to our hypothesis that older patients were challenging to get transferred, participants from ACTHs did not state such things. And the transfer decisions were perceived as well-considered based on a broad evaluation of patients' risk factors and overall health status. This was somewhat surprising. It may reflect real improvements in care but may also be the result of a recruitment of particularly positive participants. A survey to a broader group of clinicians, informed by the findings in our studies, may map the findings further.

Finally, a susceptibility to communication errors were identified in the qualitative study, yielding a potential patient safety risk. This is discussed more in the paper. It was an unexpected finding and the result of an open, explorative approach to the interviews.

6.1.4 Have we measured what matters?

Compared to what older people care about, can we claim to have done something important? Have we measured what matters?

We have predominantly reported on process and outcome measures in this thesis. It is a limitation that it is not tied closer to what older people report as important for them (81). That would be possible in a prospective study or after the NTR started to report information about patient-reported outcome measures from 2020.

I will still unequivocally argue that this matters to older people. The trauma system improves treatment and improves outcomes for older people (105). We have shown that many older people do not get the opportunity to receive those benefits. This is particularly important in a population with physical vulnerability – as comes with age (45). Physiological reserves that are unnecessarily depleted in the prehospital domain, if delays and suboptimal treatment occurs. It is biologically plausible that increased derangement from the lack of advanced interventions, targeted interventions based on precision medicine, or longer time under physiological stress, can impact outcomes in this population, although evidence to support it is currently scarce.

If more older trauma patients get managed as trauma patients because prehospital identification improves, it would most likely yield benefits that extend beyond hard endpoints. For instance regarding complications, pain, and end-of-life care. Increased focus on measuring outcome measures more closely related to older patient's wishes could strengthen the insight into how older patients do. Notably, the Utstein trauma template has not been revised since its publication in 2008. Outcome measures with impact on older patients could be a subject for future revisions.

A central premise in *Study I and II* has been that clinically significant lower care rates for older adults have been considered something negative. For example regarding undertriage. It is, however, not necessarily that simple. Because in some cases undertriage is the consequence of a deliberate decision to not activate the trauma team based on an assessment of the patient's health status. But it is not available to differentiate these cases from registry data, though it should be studied. This cannot, however, undermine the importance of highlighting a 17 percentage point difference in TTA rate (*Study I)*.

6.2 Methodological considerations

In this chapter, I discuss the methods used and their implications on the results. Additionally, I will reflect on key decisions and important challenges in the research project. Due to the different philosophical underpinnings of quantitative and qualitative methods (Chapter 4.1.1), they can and should not be evaluated using the same criteria (186). Therefore, *Studies I-III* are discussed first, then S*tudy IV*.

6.2.1 Studies I-III: Quantitative studies

In this chapter, I discuss methodological considerations pertaining to the quantitative studies (*Studies I-III)*. The outline of the discussion is framed on the Critical Appraisal Skills Programme (CASP) checklist for critical appraisal of cohort studies (187).

6.2.1.1 Design

The overall aim of this thesis was to assess whether patient safety issues exist for older patients in the Norwegian trauma system. We took on this research project by applying a retrospective cohort design, despite its limitations (Chapter 4.1.2). Why did we still choose it?

Research design should be determined by how the research question can best be answered balanced with considerations about cost and time, set up against potential pros and cons with other designs (186). For the explorative purpose of *Studies I and II's* research questions, looking at recent historical data was an advantage to provide answers which could serve as a baseline for the future. For *study III,* no big changes in the system of care for TBI patients, such as transfer guidelines, had occurred in the study period that would make historical data irrelevant.

Our aim was not to assess the effect of interventions or determine causal relationships, thus the randomized controlled study design was not suitable.

Could we have gained something valuable by running this as prospective observational studies? The potential gain we could have achieved by applying prospective study designs on the same research questions would be to set up a list of variables specifically for this setting. It could include variables of special interest that were not included in the NTR at the study period, such as cause of trauma team activation, frailty screening, or use of antithrombotic medications. And we could have recruited participants from other countries by doing an international multicenter prospective observational study. Increasing external validity is, however, not necessarily a priority as it has value in itself to assess the Norwegian setting. Adding the extra resources needed to conduct a prospective study and the time needed, it would perhaps not be feasible within the time frame of this PhD project and more importantly, the gains would not justify it. So, I conclude that overall, the retrospective cohort design was well fitted for the projects conducted. What, then, about the aforementioned limitations (Chapter 4.1.2), e.g., related to data quality, reliance on information registered by others, and the risks of bias? These relate to the studies' validity.

6.2.1.2 Validity

Questions concerning whether a research study's findings are believable and relevant to the reader's practice relate to its internal and external validity, respectively (188).

A study's internal validity refers to whether what was intended to be measured was measured. It depends on the extent to which factors threatening validity are present and how they are managed (50). According to Szklo, there are three major threats to validity; bias, confounding, and interactions (50), whereas bias can largely be divided into two main categories: selection and information bias. According to Grimes et al., these threats are present in all observational research to various degrees (188). In general, internal validity is considered low in retrospective cohort studies because there is a high risk of systematic error stemming from bias or confounding. Comparably, randomized controlled trials (RCTs) are regarded to have the highest internal validity because due to the randomization, threats to validity are equally distributed among patient groups. However, several factors that increase the internal validity were present in this thesis. This included the use of data from a clinical registry that registered patients from the whole population with a high patient coverage (>90%) and information about several important confounding factors.

External validity, the ability to generalize findings to a wider population, can be high in retrospective cohort studies. This relates to the representativeness of the study population and similarities in setting and is consequently a more subjective evaluation than the assessment of internal validity. Conversely, RCTs often have a low external validity because they often recruit participants meeting narrow inclusion criteria, which tend to be healthier and younger than the general population (188).

In the following sub-chapters, considerations of how these threats may have influenced this thesis' results and how they have been managed, are given.

6.2.1.3 Selection bias

Selection bias refers to a systematic error in the selection process of study participants with the result being a distorted measure of association between exposure and outcome (50). One advantage of using data from the NTR, which is a *national* clinical quality registry, is the high population coverage; all hospitals deliver data, all patients admitted with trauma team activation are registered, and about half of all hospitals report the identification of undertriaged patients, yielding an estimated patient coverage at >90% (114).

I want to lift two specific types of selection bias that might still have occurred in our studies.

1) Survivorship bias

Studies estimate that 50-70% of trauma deaths occur prehospital (51, 52). These deaths are difficult to quantify precisely because there is no single registry or other data source where data is registered that allows overlap with the NTR. The NTR include these patients as long as prehospital resources have been activated (Table 2), however it is well known that these deaths are challenging for registrars to get information about and therefore to register appropriately (114).

Death occurs at different times for different age groups. Older patients are more susceptible to succumbing in-hospital from multi-organ dysfunction (51, 89). However, older patients with the highest injury severity and/or severe frailty or low compensatory abilities may have a high risk of prehospital mortality. For instance, frail patients in high-energy accidents. These are speculations in the wake of existing literature. That taken into account, it would yield distorted measures about the older patients actually included. Two examples:

- In *Study I,* the assessment of injury mechanisms (*Paper 1, Figure 3*) is prone to survivorship bias. Patients severely injured by low-energy falls may be overrepresented compared to patients with traffic-related injuries. Thus, we may have an inflated measure of the impact of low-energy falls on the older patient population.
- In *Study I*, the crude mortality rate for adult and older patients were 2.9% and 13.6%, respectively. Since young patients have shown a higher prehospital mortality rate, the actual crude mortality difference from trauma may be smaller. Furthermore, as we have not accounted for the proportion of these deaths that occurred prehospital, or better yet excluded them from analysis, we have limited their comparability.

Inherent to the nature of selection bias is that it is difficult to measure and adjust for. An improvement would have been to add a sensitivity analysis where all prehospital deaths were excluded and explicitly state *in-hospital* mortality rates. We did not request the variable '*dead on arrival at scene'*, which could have given this information if the data quality is good.

2) Undertriage

Two issues related to undertriage may have caused selection bias. The identification procedures of undertriaged patients. And mismatch between study and NTR inclusion criteria.

Over the years this study applied data from (*Study I and II*: 2015-2018; *Study III*: 2015-2020), 50% of hospitals have actively identified undertriaged patients from hospital records (114). Given that older patients conduct the largest proportion of undertriaged patients, this may have yielded a falsely low undertriage rate among older patients, i.e., the true difference is actually larger. Had we considered this, we could have performed an analysis with data only from hospitals that reported searching for undertriaged patients based on data from annual reports.

We included patients with a NISS ≥9 while the NTR register undertriaged patients who meet selected criteria, including a NISS >12 (Table 2). There were good reasons for including patients with NISS as low as 9 (Chapter 4.3.1), however, this mismatch has caused that we don't have undertriaged patients with NISS 9-12 included in the cohort except if they also had proximal penetrating injuries or head AIS ≥3. This is most likely not a very large group that would distort our findings considerably.

We could have chosen other inclusion criteria, particularly the NISS threshold. Ultimately, it is a question of patient safety; we used previous literature and a pilot study to evaluate mortality rates and found that they were substantial even at lower NISS thresholds (34, 189). The inclusion criteria yielded a median NISS of 17 in *Study I's* cohort, reflecting that we captured a severely injured population. A mortality rate among older patients with NISS 9-14 of 6.1% strengthens the indication that we captured a severely injured population (*Paper I, Table 4).*

6.2.1.4 Information bias

Information bias in epidemiological studies results when information about included persons tends to be systematically flawed, leading to misclassification of patients in different exposure or outcome groups. Typically, it results from either imperfect definition of study variables or flawed data collection (50).

When using registry data, one becomes reliant on registration performed by others. Information bias is closely related to data quality. An overview of efforts by the NTR to secure high-quality data and an evaluation of the data quality in the NTR is presented in Chapter 2.3.3.4. Specifically, a detailed registration manual and annual registrar conferences aim to align coding practices. Here, possible consequences of suboptimal data quality are discussed.

Validation of registry data is central to secure trustworthy information (123). Although validation of NTR data began in 2019, it is a limitation that this thesis' studies are largely based on un-validated data. Nonetheless, the preliminary unpublished results from the validation project showed excellent agreement regarding correctness and reliability measured with Cohen's kappa (124).

Misclassification seems unlikely to have had a large influence on the most important outcome and exposure variables such as age (calculated from personal ID number) and NISS in inclusion criteria. A previous study from a Norwegian trauma center found that on expert review, the aggregated median group ISS/NISS reliability was acceptable (190). Other variables may be more susceptible to misclassification due to a known tendency to limitations in inter-rater reliability, e.g., preinjury ASA score (184), or information that inherently may be difficult to differentiate, e.g., high- and low-energy falls.

Missing data, however, was definitely present and may have led to information bias. Generally, most variables showed very low missing rates (<5%), but some important variables in the present studies showed much higher, such as prehospital and ED GCS, prehospital attendance by doctor/paramedic teams. We handled it with transparency, reported patterns in missingness (e.g., with increasing injury severity and across groups we compared), and in study III with multiple imputation. Variables with a high degree of missingness should be interpreted with caution.

Missing data about physiological variables was a problem. To a large extent, we could not use that valuable information because of a high degree of missing (up to 40% for respiratory rate), increasing with increasing injury severity, thus not missing at random. This is a well-known problem in emergency medicine research (191). It is very problematic that an important predictor of mortality, the prehospital physiological status, is not available for research. A future with automatic data capture is welcome, as is achieved by the Victorian State Trauma Registry, Australia. They report great improvements in prehospital data quality after they began data capture from the prehospital service's information system (192).

We experienced transfer status as unreliably reported, which is nothing new (193). This led to in-depth reviews of multiple variables for all patients with multiple registrations to determine primary and secondary hospitals. Furthermore, patients with registrations from only one hospital, but with information about transfer in other variables were scrutinized, and a triangulation of information was used to determine transfer status. This is allegedly improved in NTR's new registration database.

6.2.1.5 Confounding

Confounding appears when *"a non-causal association between a given exposure and an outcome is observed as a result of the influence of a third variable (or group of variables)* (50). In *Studies I and II* we did not adjust for confounders because they were designed as descriptive studies.

In *Study III*, we identified confounding variables through the literature and discussions. They were included in the study as described in Chapter 4.3.3. It is a limitation of the study that information about some confounding factors, such as frailty and use of antithrombotic medications, was not available from the registry and therefore not able to adjust for. Importantly, the qualitative study also identified preinjury functional impairments as important. These findings should inform future studies.

6.2.1.6 Exposures and outcomes

We published the thesis' protocol to show transparency about our intended exposure and outcome measures. As there is no commonly accepted international registry for observational studies, as clinicaltrials.gov is for clinical trials, this is one way to achieve openness. The goal is to counteract fishing for significant *P* values in large databases.

Trauma patients exposed to advanced age were the primary objects studied in this thesis. Age is a reliable and easily obtainable measure. But it is also a one-dimensional way to separate and compare populations. Arguably, the heterogeneity regarding preinjury health deficiencies is larger among older patients. Hence, an age dichotomy can be seen as over-simplistic. Some studies have compared more age groups (12). Others have assessed various outcomes across age as a linear variable, as we did in *Study III* when age was one of several exposures that could have influence on the outcome under study. However, in *Studies I and II,* the point was to make a design that allowed for a description of trauma processes and outcomes across a broad range of measures. A bird's-eye perspective. Therefore, the age dichotomy was reasonable. And it was supplemented with information on ten-year age subgroups in some tables and figures to convey more information to the reader.

A study's outcome measures are defined to let the reader understand what you measure to answer your aim. I do believe better-defined outcome measures would have improved the structure and readability of particularly *Paper II*.

Finally, I want to raise a discussion about a conceptual premise for our evaluation of outcomes in this thesis. We generally argue that no differences in observed rates should be considered standard of care for older patients. This is based on the assumption that younger patients' care is as good as can be currently delivered and can therefore serve as the comparator. However, the age group 16-64 years may span too wide to be one comparator group. And in the heterogeneous group of patients ≥65, it is to be expected that in some cases, refraining from highest-level care is ethically right, which may be reflected in our results.

6.2.1.7 Deviations from protocol

Study I: We wrote that we wanted to report on the ISS, prehospital and ED interventions, and length of stay. ISS was discarded to focus on one measure of severity throughout the project, which was NISS. Prehospital and ED interventions was chosen to be covered in *Study II*. LOS was discarded because? I am not sure.

Study II: Dropped the "secondary endpoint" about physiological variables due to data quality.

Study III: We narrowed the focus of the study towards admission and transfer rates (care pathways). We discarded reporting of transport methods and physiology to keep a stringent focus on factors associated with interhospital transfer.

6.2.2 Study IV: Qualitative study

In this chapter and the corresponding sub-chapters, I will discuss methodological considerations pertaining to *Study IV*. The outline of the discussion is framed on the CASP checklist for critical appraisal of qualitative research (194).

6.2.2.1 Design and analysis

A qualitative design was appropriate given the study's aim of exploring the decision-making process regarding interhospital transfer, necessitating to obtain views from responsible personnel. We chose to conduct focus group interviews as the method of data collection, because of the reasons listed previously (Chapter 4.4.2). Individual interviews were considered, but discarded because it would probably not yield richer or more open and honest discussions because the topics covered were overall not sensitive or highly personal, which are barriers to successful qualitative research. They are also overall more time demanding.

Qualitative methodologies are very flexible, and allow for making changes to the study design during the research process according to the experiences underway (151). For instance, one can change the interview guide, the target participants, number of interviews – or even method of data collection if deemed beneficial. Retrospectively, I think it would have been interesting to supply the focus group interviews with ethnographic observations, particularly on the neurosurgical side. To observe the setting of the decision-making process, the workload on-call, and management of consultations from outside hospitals. It could have provided meaningful insight, potentially combined with follow-up interviews. The extra resources it would have demanded in time to conduct and to learn an extra set of skills would, however, most likely have been outside the scope of this PhD project.

Thematic analysis is just one of many qualitative methodologies. The benefits that contributed to a successful execution is its simpleness, it was taught at the PhD course, it is well suited for explorative inductive designs, and it does not require extensive knowledge about theory.

6.2.2.2 Recruitment and data collection

We applied a purposeful selection strategy. The eligibility criteria were met, and they secured recruitment of participants with balanced sex, specialties, and experience, and from hospitals with different sizes and transfer differences. Thus, the purposeful selection could be considered successful. On the other hand, we do not know the characteristics of the eligible candidates that did not participate at each hospital. As discussed in the paper, the statements the surgeons at ACTHs gave were more positive than anticipated. Perhaps this is related to who consent to participate, or other factors such as experience. Matters of data saturation is discussed elsewhere.

7 Ethical considerations

Research ethical considerations regarding this thesis were presented in Chapter 4.6. Here, I want to briefly draw attention to clinically relevant ethical considerations that are close to the topic of trauma in older patients.

Whenever I teach about trauma in older patients, it evokes questions related to ethics. For example, questions founded in participants' own experiences about the correct treatment intensity, patients' wishes, or where things have gone wrong. It indicates that when people have had encounters with older trauma patients, ethical considerations are never far away.

Therefore, I want to briefly address the underlying premise of this thesis, that all older patients have the right to high-quality trauma care when injured. High-quality care does not mean doing everything all the time. It means making decisions with respect to fundamental ethical principles of autonomy, beneficence, non-maleficence, and justice to serve the individual's best interests. In some cases, and more often in older people than in children and adolescents, that require limitations in treatment.

However, if these decisions are done without all facts on the table, or without the necessary skills and insight into realistic prognostic trajectories, preventable harm may occur. Therefore, I believe these decisions are best made by clinicians with trauma experience after diagnostic imaging has been performed, i.e., predominantly at hospitals. This is in line with this thesis' focus on discrepancies in care levels, particularly in the prehospital phase.

8 Conclusions

Older trauma patients in Norway were at risk of receiving less advanced prehospital care than younger adults. They were less often attended by doctor/paramedic teams, less often transported by air ambulance, and less often received advanced interventions despite similar injury severity.

Older trauma patients in Norway were less often admitted to hospitals with a trauma team activated and were less often receiving care at a trauma center than younger adults. However, when admitted by a trauma team, they underwent radiological imaging at a similar rate as younger adults, and advanced interventions less often only when very severely injured.

Older trauma patients in Norway had a 4.7 times higher unadjusted mortality rate and were less frequently discharged home from definitive care.

Among patients who sustained an isolated moderate-to-severe TBI, older patients were more likely than younger adults to be primarily admitted to a hospital without neurosurgical resources. Interhospital transfer to a neurotrauma center was associated with increasing injury severity, and a reduced transfer probability was associated with increasing age and comorbidity and increasing distance between hospitals in adjusted analysis.

Surgeons at non-neurosurgical hospitals and neurosurgeons at neurotrauma centers made transfer decisions based on several clinical and system-level factors. They constantly considered factors in light of their impact on the chance of a favorable outcome. Preinjury health status, including advanced age, comorbidities, and functioning, was considered to have a dose-response effect on reduced transfer probability. Decisions were patient-centered and included an assessment of individual patients' risk factors and overall health status.

9 Future perspectives

"The ultimate goal is to manage quality. But you cannot manage it until you have a way to measure it, and you cannot measure it until you can monitor it".

Florence Nightingale (1820-1910)

Florence Nightingale's famous quote captures the essence of quality improvement and remains relevant even today; monitoring trauma care by the NTR has enabled us to measure quality. Yet, the quote does not address what comes after; how can we shape a better future for older trauma patients, based on our findings? Given our insights, what practical directions can be proposed?

Trauma systems have proven effective for injury prevention and treatment using a standardized and uniform approach for all patients. A study from Norway has shown improved outcomes over time for older patients managed in a maturing trauma system (105). This indicates benefit of systematic trauma care, even though the study identified some of the same challenges as in our studies, such as undertriage. I am convinced that the future of older patients' trauma care lies within the existing trauma system framework.

Some changes may be made in order to achieve future improvements. For instance, to reduce the number of patients not attended by a trauma team, all older patients with suspected injuries could receive prompt physician assessment upon ED arrival. Two-tiered trauma teams, one small and one extended, may reduce undertriage of older patients (132). As medical problems frequently coexist with trauma, e.g., as concurrent acute illness or exacerbation of comorbidity, internal medicine physicians, preferably geriatricians, should be actively involved both initially and throughout the care for older adults (180).

Resistance towards activating trauma teams for older patients can occur, perhaps rooted in perceptions about a greater benefit for younger patients. This perception could be addressed by teaching personnel about trauma care's importance for older patients, albeit more rarely in an action-filled manner than for younger adults. Furthermore, reporting and tracking outcome measures that are meaningful endpoints for older patients and how they improve from streamlined trauma care may challenge these perceptions. Such outcome measures could be complication and delirium rates (which are associated with mortality), opioid-sparing interventions such as peripheral nerve blocks, and good end-of-life decisions. Finally, emerging evidence shows an important role of frailty screening in targeting individual decision-making (16). Frailty screening could be considered implemented in the national trauma plan.

In the prehospital arena, challenges are more intricate. However, an advantage stems from trauma system similarities across countries, which makes research findings transferable. Surveillance of international literature and implementation of changes, when evidence is strong, should be considered. For instance, much work has been done to improve triage criteria. No evidence suggests implementing a different field triage tool in Norway now. In fact, studies suggest that current criteria are better than their reputation because some of the poor results stem from non-adherence to protocol (177-179). Dr. Platts-Mills' insightful commentary about "thinking slow inside the golden hour" suggests that prehospital personnel's intuition ('fast thinking system') leads to wrong judgments in older trauma patients due to the reasons mentioned earlier (195, 196). Thus, forcing them to use the 'slow thinking system' by using the triage tool as a checklist and justify deviations from protocol may be the way forward.

A hopeful perspective about a future where artificial intelligence is everywhere, encompass intelligent decision support tools integrated into paramedics' digital devices and smart data capture for registries. In the era of precision medicine, perhaps new or more widespread use of existing devices may lead to breakthroughs in identifying injured older adults.

Regarding access to the most advanced prehospital resource, the doctor/paramedic teams, several questions remain unanswered. Who benefits from such management, and who does not? How do EMCCs identify older trauma cases that lead to a request for HEMS services, and how do HEMS doctors evaluate them? Which older trauma patients are currently being attended by doctor/paramedic teams? These are research priorities, and we are currently conducting a study on the final question.

Interhospital communication about isolated TBI patients showed susceptibility to error in our study. Considering the significance of frailty in TBI outcome research and its overlap with the clinical factors influencing transfer, it seems prudent to explore the inclusion of the Clinical Frailty Scale in these discussions.

Lastly, but no less important, the quest for better trauma care for older people must be viewed in light of the overall healthcare resources and workforce situation in the future (197). Avoiding unnecessary wear and tear of the people, for instance by high overtriage rates and frequent trauma team activation on "futile" cases, is important to keep the system sustainable.

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10 Papers

10.1 Paper I

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Epidemiology of geriatric trauma patients in Norway: A nationwide analysis of Norwegian Trauma Registry data, 2015–2018. A retrospective cohort study

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ABSTRACT

Introduction: Geriatric patients have a high risk of poor outcomes after trauma and is a rapid-increasing group within the trauma population. Given the need to ensure that the trauma system is targeted, efficient, accessible, safe and responsive to all age groups the aim of the present study was to explore the epidemiology and characteristics of the Norwegian geriatric trauma population and assess differences between age groups within a national trauma system.

Materials and methods: This retrospective analysis is based on data from the Norwegian Trauma Registry (2015-2018). Injury severity was scaled using the Abbreviated Injury Scale (AIS), and the New Injury Severity Score (NISS). Trauma patients 16 years or older with NISS $\geq$9 were included, dichotomized into age groups 16–64 years (Group 1, G1) and $\geq$65 years (Group 2, G2). The groups were compared with respect to differences in demographics, injury characteristics, management and outcome. Descriptive statistics and relevant parametric and non-parametric tests were used.

Results: Geriatric patients proved to be at risk of sustaining severe injuries. Low-energy falls predominated in G2, and the AIS body regions 'Head' and 'Pelvis and lower extremities' were most frequently injured. Crude 30-day mortality was higher in G2 compared to G1 (G1: 2.9 vs. G2: 13.6%, $P<0.01$) and the trauma team activation (TTA) rate was lower (G1: 90 vs. G2: 73%, $P<0.01$). A lower proportion of geriatric patients were treated by a physician prehospitally (G1: 30 vs. G2: 18%, [NISS 15–24], $P<0.01$) and transported by air-ambulance (G1: 24 vs. G2: 14%, [NISS 15–24], $P<0.01$). Median time from alarm to hospital admission was longer for geriatric patients (G1: 71 vs. G2: 78 min [NISS 15–24], $P<0.01$), except for the most severely injured patients (NISS>25).

Conclusion: In this nationwide study comparing adult and geriatric trauma patients, geriatric patients were found to have a higher mortality, receive less frequently advanced prehospital treatment and transportation, and a lower TTA rate. This is surprising in the setting of a Nordic country with free access to publicly funded emergency services, a nationally implemented trauma system with requirements to pre- and in-hospital services and a national trauma registry with high individual level coverage from all trauma-receiving hospitals. Further exploration and a deeper understanding of these differences is warranted.

Introduction

Trauma is a major cause of mortality and reduced quality of life, and accounts for approximately 10% of the global burden of disease

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[1]. To reduce avoidable death and disability, it is essential to have well-prepared systems with adequate distributions of resources, knowledge, and personnel [2,3]. Trauma systems are obliged to continuously improve quality and patient safety and in this respect epidemiological studies are important to identify high-risk populations which preventive measures can be directed towards [4,5]. Several mature trauma systems experience a demographic transition into older populations, and the impact of geriatric trauma is already showing [6-9]. Adaptation to ongoing changes in the trauma population is one of the major challenges for modern, evolving trauma systems [10].

In the UK, a study from the Trauma Audit and Research Network (TARN) demonstrated that the proportion of trauma patients above 75 years of age had increased from 8.1% in 1990 to 26.9% in 2013 [11]. Fröhlich et al. recently demonstrated that severely injured geriatric trauma patients in the TraumaRegister DGU were overrepresented compared to the general German population [12]. The global population is ageing [13] and the European Union predicts an increase of inhabitants aged 65 years and above from 101 million in 2018 to 149 million by 2050 [14]. As a consequence, the burden of geriatric trauma is uniformly expected to increase.

Multiple studies have found geriatric patients to be vulnerable within the trauma system, prone to poor outcomes. Compared with younger patients with similar injury severity, geriatric patients have a higher mortality and morbidity, a lower trauma team activation rate, higher complication rates, and high risk of a poor functional outcome [6,15-21]. In addition, decreased transfer likelihood [22], and low trauma center utilization has been found [7]. However, improvements in outcome is achievable, as demonstrated by a Norwegian study by Ringen et al. which assessed the mortality for geriatric patients in an evolving trauma system over 12 years. They found a general survival benefit, with an OR of 0.77 if admitted in the second half of the time period, possibly due to multifactorial improvements over time [23].

Geriatric patients are characterized by having limited physiologic reserves and a high incidence of comorbidity, frailty and polypharmacy [17,24] which can influence the clinical presentation after injury to appear within normal range and preclude the triage decision [25,26]. Field triage algorithms for trauma seek to use all available information about physiological parameters, anatomic injury, mechanism of injury and certain special considerations, yet older patients are consistently found to have a high risk of undertriage to trauma centers and trauma team admissions [19,27,28]. Even when meeting field triage criteria, geriatric patients are less likely to be admitted to a trauma hospital [29].

Norway has a population of 5.4 million people [30], of which approximately 12% are 70 years or older, projected to be 20% by 2060 [31]. It is a high-income country with a publicly funded health care system and a population localized in a mix of urban and rural areas with long geographic distances. Approximately eighty-six percent of the population lives in central areas, defined by proximity to workplaces and services [32]. A nationwide trauma system is implemented [33], describing uniform requirements to all ambulance services and trauma-receiving hospitals. Four level I or II equivalent trauma centers (TC) and 34 local acute care trauma hospitals (ACTH), equivalent to level III TCs [4], receive trauma patients. All these hospitals deliver data to the Norwegian Trauma Registry (NTR) which has a high coverage on hospital and patient level [34]. Rehabilitation services are offered both within specialized centers and in nursing homes in local communities.

Improvement in trauma care requires detailed knowledge of the epidemiology of trauma, patient demographics, interventions, clinical outcomes, and the patient's journey throughout the complete treatment chain [35,36]. New knowledge about the rapid-increasing and vulnerable geriatric trauma population is necessary to ensure that the system of trauma care is targeted, efficient, accessible, safe and responsive to all age groups. Given the lack of knowledge about this population in Norway, our aim was to describe the Norwegian geriatric trauma population by assessing differences in demographic and epidemiological characteristics between age groups, as well as describing injury characteristics and outcomes with data from the NTR.

Methods

Study design and data sources

A retrospective cohort study of all trauma cases in Norway between January 1, 2015 and December 31, 2018 was performed, using NTR data. The protocol for this study was published in advance [37].

Study sample

All trauma-receiving hospitals (40 hospitals in the study period) delivered data to the Norwegian Trauma Registry from all parts of the treatment chain; from the pre-hospital phase through emergency department, critical care unit (CCU) and rehabilitation phases. Patients who meet the following inclusion criteria are registered: Admitted through trauma team activation (TTA), admitted without TTA but found to have penetrating injuries to head, neck, torso, or extremities proximal to knee or elbow, head injury with Abbreviated Injury Scale (AIS) ≥ 3 or New Injury Severity Score (NISS) > 12 [34]. An estimated 95% of patients who meet these criteria are included in the registry [34]. Patients declared dead before hospital arrival after initiation of prehospital management do also meet the inclusion criteria, but because of inadequate information, the registry has low coverage of those who die at the injury site. Fifty percent of the hospitals identified undertriaged patients, and among these are all the largest hospitals, covering the majority of patient volume [34,38].

Data collection is based on the Utstein template and includes detailed information on demographics, injury characteristics, comorbidities, pre- and in-hospital management and interventions and outcomes [39]. Injuries are coded by Association for the Advancement of Automotive Medicine (AAAM) certified registrars according to the AIS manual version 2005, update 2008 [40]. The AIS methodology assigns a code to all injuries which designates body region and injury severity, ranging from 1 (minor) to 6 (maximum and currently untreatable). This is in turn used to calculate the NISS by summarizing the square of the three highest AIS severity scores irrespective of body region [41].

The study population was dichotomized by age into 'Group 1, G1' aged 16–64 years and 'Group 2, G2' aged 65 years and above. Pre-specified sub-categories were defined as age-intervals 65–74, 75–84, and ≥ 85 years [37]. NISS was grouped into intervals (9–14/ 15–24/ ≥ 25) in accordance with the AIS severity description [40]. For analysis of proportion of severe injuries (AIS≥ 3) according to injury locations, patients with multiple injuries in the same body region was counted only once for each region.

Patients aged 16 years or more with NISS ≥ 9 registered in the NTR between January 1, 2015 and December 31, 2018 were included. Patients with missing information about age or AIS were excluded, mainly patients with foreign residency.

Norwegian Trauma Registry variables

We collected data on age, gender, pre-injury physical status as defined by the American Society of Anesthesiologists physical status classification system (PPS-ASA) [42,43], injury location, AIS, NISS and mechanism of injury (MOI), trauma team activation (TTA), mode of transportation, highest level of prehospital care, discharge

Table 1
Overview of data item operationalization from original NTR variable.

Data item	New categories
ASA	ASA 3 and 4 = ASA 3⁺. ASA 4 = 0.9% of the study population.
Place of injury, utilizing Centrality Index of Norway	Category 1–4: "Urban Norway". Category 5 and 6: "Remote Norway"
Discharge destination from definitive care	"CCU (higher treatment level)" and "CCU (same level of care)" = "CCU".
Mechanism of injury	"Traffic: Other" and "Explosions" merged with "Other".
Type of transportation	Fixed- and rotor-wing merged to "Air ambulance". Fixed-wing = 0.6% of the study population. "Private/public vehicle", "walk-in" and "police" merged with "Other".
Highest level of prehospital care provider	"Level I: No field care" = "Other". "Level II: Basic Life Support" and "III: Advanced Life Support, no physician present" = "Ambulance personnel-led care".
Highest level of in hospital care	"Emergency department" and "Operating Theatre" merged with "Other". "High dependency unit" and "Critical care unit" merged.
Time	Outliers >24 h excluded from analysis.

destination and 30-day mortality. Data on mortality appear in two different variables: *30-day mortality* and *Discharge destination; In-hospital mortality*. The latter represents patients who die before any discharge disposition could be made, while 30-day mortality include all deaths occurring within 30 days, irrespective of where it happened. Low-energy falls (LEF) are defined as falls from standing or less than 1 m height, and high-energy falls (HEF) as falls from >1 m height, with emphasis on the total amount of energy involved, not strictly restricted to meters.

Seven data items were re-categorized from its original NTR definition (Table 1). An overview of the original categories of each variable is presented elsewhere [39,44]. Each score component has a category for "unknown" information which was analyzed as "missing". There were no missing data for *transfer status* or *definitive care*. Other variables had less than five percent missing data, except from *type of transportation* (6.4%), *highest level of prehospital care provider* (10.1%), and *time from alarm to hospital arrival* (17.9%). The distribution of missing data was significantly different between Group 1 and Group 2 for the latter two variables. No imputation was performed.

Injury location was registered on municipality level and mapped to the Centrality Index of Norway (CIN), a continuous variable which is grouped into six categories, from highest (1) to lowest (6) centrality [32]. These categories are based on the number of workplaces and service industries available within a 90-minute drive. The capital, Oslo, and its surrounding municipalities, are category 1, all the second largest cities in Norway are category 2, the surroundings to these cities and regional towns are category 3 and 4, and rural municipalities are category 5 and 6.

Data on the age distribution of the adult Norwegian population was obtained from Statistics Norway for the years of the study period (2015–2018).

Statistics

Data is reported as numbers and percentages for categorical variables and continuous variables are presented as means and standard deviations (SD) or medians and interquartile range (IQR). Differences between age groups were evaluated with Pearson's chi-squared test or Mann-Whitney *U* test for categorical data. For continuous variables with large sample sizes, non-normal distribution, and unequal variances, the Welch's *t*-test was performed. A *P* value <0.05 (two-tailed) was considered to be statistically significant. Analyses were performed using SPSS v.25 (IBM Corp., Armonk, NY, USA).

A sensitivity analysis was performed, assessing differences in 30-day mortality and TTA between age groups stratified by injury severity, after excluding patients with significant comorbidity (ASA 3–4) and those with highest age (≥85 years).

Ethical considerations

All patients receive written information about the registry, including the opportunity to access the data recorded and to deny registration. De-identified data was extracted. The study was approved by the Oslo University Hospital data protection officer (No. 19/16,593).

Results

A total of 11,403 patients met the inclusion criteria (Appendix 1), of which 7668 (67%) were 16–64 years of age (Group 1) and 3735 (33%) were 65 years or above (Group 2). Demographic data are presented in Table 2. The median age was 43 years (IQR 28–54) in Group 1 and 76 years (IQR 70–84) in Group 2. The majority of patients were men (77% of Group 1, 60% of Group 2), except in the age-intervals with highest age (≥85 years), where female patients dominated (Fig. 1). In Group 1 the median ASA score was significantly lower than in Group 2 (1 [IQR 1–2] vs. 2 [IQR 2–3]). The proportion of injuries happening in urban areas did not differ between the groups.

Patients 65 years and above constituted 33% of the study cohort but only 16.5% of the Norwegian population (Fig. 2). This overrepresentation of patients with severe trauma is seen from age 48 years, as well as from 16 to 23 years, while young adults (24–45 years) show a decreased risk of severe injuries.

Injury characteristics

Blunt trauma was significantly more prevalent in Group 2 than in Group 1 (98% vs. 94%), as demonstrated in Table 3. 58% of all patients in Group 2 had a NISS of ≥15, significantly higher than 53% in Group 1. The median NISS was 17 in both age groups.

Injury mechanisms are presented by age categories in Fig. 3, with underlying numbers presented in Appendix 2. The prevalence of low-energy falls ranged from 5% among patients aged 16–24 years to over 60% among patients ≥85 years. The three most frequent mechanisms of injury in Group 1 were high-energy falls (28%), motor vehicle injuries (17%) and bicycle injuries (12%), compared to low-energy falls (40%), high-energy falls (29%) and motor vehicle injuries (13%) in Group 2. Among all ages, high-energy falls peaked in age group 65–74 years (35%) before it decreased with increasing age. Traffic-related injuries accounted for 44% of all injuries in the 35–44 years age interval, decreasing with increasing age. Two peaks of motor vehicle injuries were found; one in age interval 16–24 years, the second in age interval 75–84 years.

The AIS body regions head, thorax, and pelvis and lower extremities were the most frequently severely injured body regions in all age intervals (Fig. 4). Geriatric patients had higher proportions of severe head and pelvis or lower extremity injuries com-

Table 2
Demographic characteristics of the two age groups.

	Group 1 16–64 years, n = 7668 (67%)	Group 2 ≥65 years, n = 3735 (33%)	P value
Median age	43 (28–54)	76 (70–84)	NP
Male sex, n (%)	5913 (77.1)	2246 (60.1)	<0.01
Preinjury ASA physical status[a], median (IQR)	1 (1–2)	2 (2–3)	<0.01#
ASA 1	5177 (69.7)	804 (22.2)	<0.01
ASA 2	1820 (24.5)	1620 (44.8)	
ASA 3*	432 (5.8)	1191 (32.9)	
Place of injury[b]			0.18
Urban Norway	6033 (83)	3009 (84.1)	
Remote Norway	1233 (17.0)	571 (15.9)	

Abbreviations: IQR, inter quartile range; NP, not performed; ASA, American Society of Anesthesiologists.
#Mann-Whitney *U* test.
ASA 3* includes 21 (G1) and 81 (G2) patients with ASA 4.
Missing data for G1 and G2 , respectively: [a]ASA: 3.1% and 3.2%. [b]Place of injury: 5.2% and 4.1% .

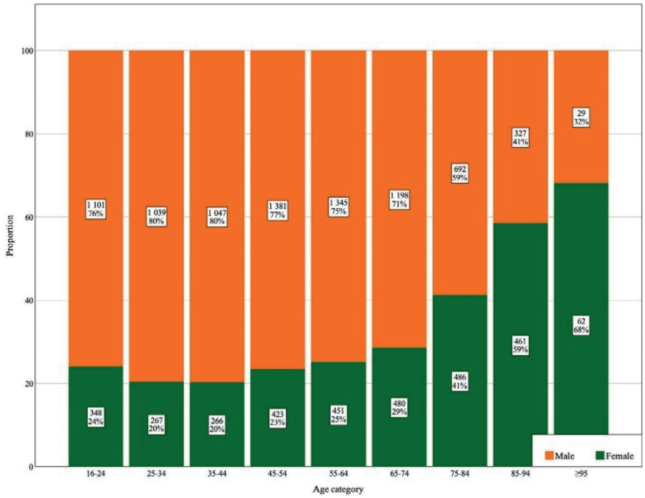

Fig. 1. Proportion and absolute numbers of male and female patients according to age category.

pared to younger age groups. Underlying numbers are presented in Appendix 3.

Level of care

Outcome and level of care stratified by injury severity and age group are presented in Table 4. The proportion of patients in Group 2 receiving physician-led care ranged from 13 to 28% with increasing injury severity, compared to 22 to 47% in Group 1. The rate of air ambulance transports (Group 2: 10 to 19% vs. Group 1: 16 to 33%) was significantly lower in all injury severity subgroups. Trauma team activation rate was significantly lower for patients in Group 2 within all injury severity groups, ranging from 71 to 79%, compared to 86 to 92% in Group 1. Crude 30-day mortality was significantly higher in Group 2, both when stratified by age (2.9 vs. 13.6%, Table 3) and injury severity ([NISS 9–14]: 0.3 vs. 6.1%, [NISS 15–24]: 0.7 vs. 7.7%, Table 4). The results of the sensitivity analysis demonstrated diminished differences after excluding patients with ASA 3-4 or age ≥85 years, but still significant in the most severely injured group (Table 5).

Patients in Group 2 with NISS≥15 or NISS ≥25 were to a significantly lesser extent transferred to a TC from an ACTH compared with patients in Group 1. The proportions of patients receiving definitive care at a TC are also significantly lower for Group 2 patients in all injury severity groups. The mean time from alarm to hospital arrival was significantly longer for patients in Group 2 with a NISS <25, however for the most severely injured, the mean time was similar between Group 1 and Group 2. There was a significant difference in discharge destination (Table 3), where 60% of patients in Group 1 was discharged home from definitive care, compared to 38% of patients in Group 2. The proportion of patients discharged to "Nursing home" was significantly higher in Group 2 (20.5%) than in Group 1 (4%), rising with increasing age to 40% for those 85 years and above.

Discussion

The aim of this study was to describe the Norwegian geriatric trauma population by assessing differences in demography, epidemiology, outcome and level of care between age groups, as well

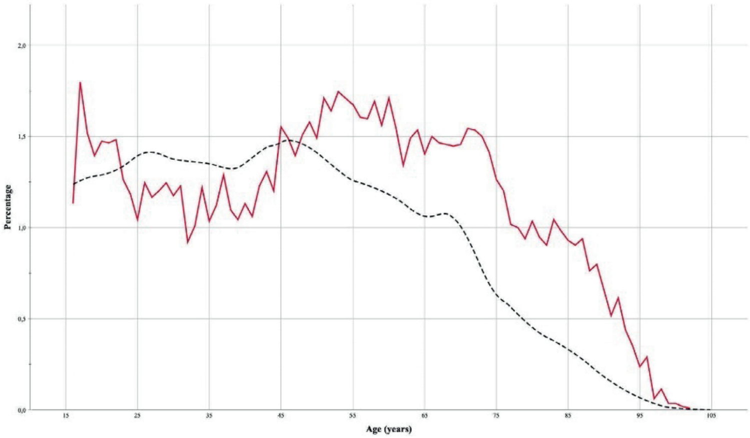

Fig. 2. The age distribution of trauma patients in the study cohort (solid line) demonstrates an increased risk of trauma from age 16–23 and from age 48. The dotted line displays the average age distribution of the Norwegian population in 2015 to 2018.

Table 3
Injury characteristics and outcome by age.

	Group 1: 16–64 years, n = 7668 (67%)	Group 2: ≥65 years, n = 3735 (33%)	P value	65 – 74 years, n = 1678 (45%)	75 – 84 years, n = 1178 (32%)	≥ 85 years, n = 879 (23%)
Dominating type of injury[a], n (%)			<0.01			
Blunt	7053 (94.2)	3570 (98.3)		1582 (97.6)	1135 (99.0)	853 (98.6)
Penetrating	432 (5.8)	63 (1.7)		39 (2.4)	12 (1.0)	12 (1.4)
New Injury Severity Score, n (%)			<0.01			
9–14	3637 (47.4)	1560 (41.8)		688 (41.0)	475 (40.3)	397 (45.2)
15–24	2226 (29.0)	1215 (32.5)		561 (33.4)	401 (34.0)	253 (28.8)
≥25	1805 (23.5)	960 (25.7)		429 (25.6)	302 (25.6)	229 (26.1)
Median (IQR)	17 (12–22)	17 (12–25)	<0.01#	17 (12–25)	17 (13–25)	17 (13–25)
Trauma team activation[b], n (%)			<0.01			
Yes	6832 (89.8)	2711 (73.3)		1353 (81.4)	836 (71.6)	522 (60.0)
No	773 (10.2)	989 (26.7)		310 (18.6)	331 (28.4)	348 (40.0)
Discharge destination from definitive care[c], n (%)			<0.01			
Home	4564 (60.1)	1412 (38.2)		824 (49.6)	418 (35.8)	170 (19.5)
Rehabilitation	581 (7.6)	212 (5.7)		117 (7.0)	61 (5.2)	34 (3.9)
In-hospital mortality	198 (2.6)	351 (9.5)		75 (4.5)	113 (9.6)	163 (18.7)
Critical care unit	751 (9.9)	363 (9.8)		192 (11.6)	123 (10.5)	48 (5.5)
Somatic hospital ward	1200 (15.8)	602 (16.3)		295 (17.8)	200 (17.1)	107 (12.3)
Nursing home*	303 (4.0)	758 (20.5)		158 (9.5)	252 (21.6)	348 (40.0)
30-day mortality[c], n (%)			<0.01			
Dead	215 (2.9)	500 (13.6)		97 (5.9)	161 (13.9)	242 (27.8)
Alive	7270 (97.1)	3166 (86.4)		1542 (94.1)	997 (86.1)	627 (72.2)

Abbreviations: IQR, inter quartile range; TTA, trauma team activation.
*Inlcudes discharge to psychiatric institutions, prison and other [39].
#Mann Whitney *U*.
Missing data for G1 and G2, respectively: a, Dominating injury: 2,4% and 2,7%. b, TTA: 0,8% and 0,9%. c, Discharge destination: 0,9% and 1,0%. d, 30-day mortality: 2,4% and 1,8%. .

as describing injury characteristics. We found geriatric patients (Group 2) to have consistently higher mortality than adult patients (Group 1), receive less advanced prehospital treatment and transportation, and a lower trauma team activation rate. In a country with a homogeneous population, where a national trauma plan is implemented and with a high coverage national trauma registry in place, there are strong reasons to believe that the findings represent true undertriage and inferior services to geriatric patients.

Geriatric trauma patients constituted a substantial part of the study cohort (33%) and demonstrated an increased risk of severe injury compared to the proportion geriatric patients constitute in the Norwegian population (17%), as demonstrated in

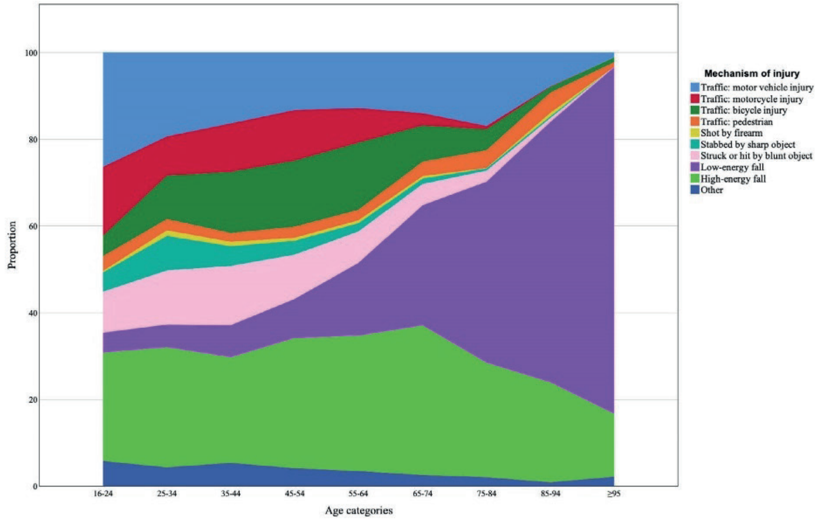

Fig. 3. Distribution of mechanism of injury according to patient age category.

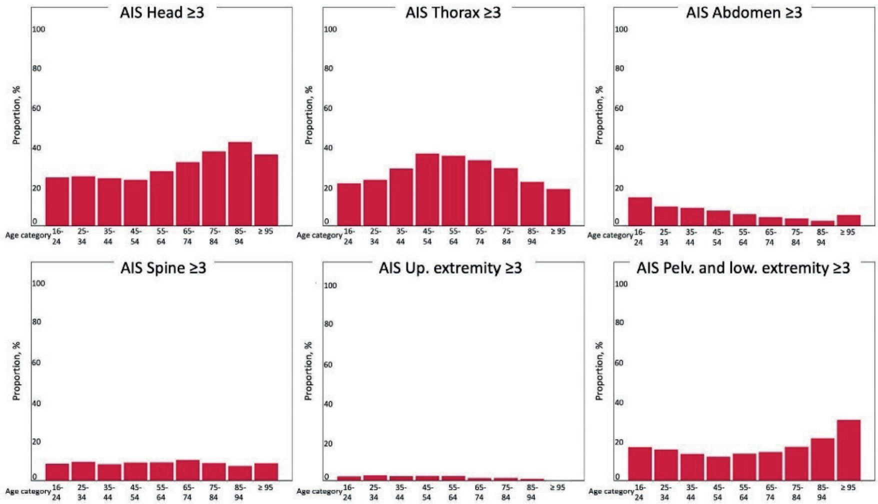

Fig. 4. Proportion of severe injury (AIS ≥3) according to injury location (head, thorax, abdomen, spine, upper extremities and lower extremities) and age intervals.

Table 4
Outcome and level of care by age group and injury severity.

	NISS 9 through 14			NISS 15 through 24			NISS 25 through 75		
	16–64 years, $n = 3640$ (47.5)	>65 years, $n = 1567$ (41.9)	P-value	16–64 years, $n = 2234$ (29.1)	>65 years, $n = 1227$ (32.9)	P-value	16–64 years, $n = 1794$ (23.4)	>65 years, $n = 941$ (25.2)	P-value
Type of transportation, n (%)			<0.01			<0.01			<0.01
Ground ambulance	2734 (79.1)	1245 (84.6)		1447 (70.0)	929 (81.4)		1069 (63.7)	656 (76.0)	
Air ambulance	551 (15.9)	141 (9.6)		500 (24.2)	158 (13.8)		552 (32.9)	164 (19.0)	
Other	170 (4.9)	85 (5.8)		119 (5.8)	54 (4.7)		58 (3.5)	43 (5.0)	
Highest level of prehospital care provider, n (%)			<0.01			<0.01			<0.01
Physician-led care	717 (21.6)	180 (12.9)		597 (30.2)	199 (18.2)		770 (47.1)	227 (27.5)	
Ambulance personell-led care	2564 (77.1)	1201 (86.3)		1348 (68.3)	886 (80.9)		849 (51.9)	592 (71.8)	
Other	46 (1.4)	10 (0.7)		29 (1.5)	10 (0.9)		16 (1.0)	6 (0.7)	
Trauma team activation, n (%)			<0.01			<0.01			<0.01
Yes	3334 (92.3)	1115 (71.9)		1904 (85.9)	860 (70.8)		1594 (89.7)	736 (78.8)	
No	277 (7.7)	436 (28.1)		313 (14.1)	355 (29.2)		183 (10.3)	198 (21.2)	
Transfer status, n (%)			0.69			<0.01			<0.01
Transferred	155 (4.3)	50 (3.2)		263 (11.8)	102 (8.3)		370 (20.6)	125 (13.3)	
Not transferred	3485 (95.7)	1517 (96.8)		1971 (88.2)	1125 (91.7)		1424 (79.4)	816 (86.7)	
Definitive care, n (%)			0.03			0.02			<0.01
Acute care trauma hospital	2257 (62.1)	1018 (65.3)		1035 (46.5)	616 (50.7)		399 (22.1)	362 (37.7)	
Trauma center	1380 (37.9)	542 (34.7)		1191 (53.5)	599 (49.3)		1406 (77.9)	598 (62.3)	
30-day mortality, n (%)			<0.01			<0.01			<0.01
Dead	10 (0.3)	93 (6.1)		16 (0.7)	92 (7.7)		189 (10.7)	315 (33.4)	
Alive	3535 (99.7)	1434 (93.9)		2152 (99.3)	1105 (92.3)		1583 (89.3)	627 (66.6)	
Highest level of in-hospital care, n (%)			<0.01			<0.01			<0.01
General ward	665 (18.5)	368 (23.9)		274 (12.4)	202 (16.7)		67 (3.7)	94 (9.9)	
Critical care unit*	2590 (72.0)	996 (64.6)		1771 (80.1)	906 (75.1)		1644 (91.6)	815 (85.7)	
Other	343 (9.5)	178 (11.5)		165 (7.5)	98 (8.1)		83 (4.6)	42 (4.4)	
Time from alarm to hospital arrival (min), median (IQR)	63 (39–100)	77 (48–117.5)	<0.01#	71 (43–105)	78 (47–121)	<0.01#	67 (38–105)	69 (44–105)	0.5#

Abbreviations: NISS, New Injury Severity Score; IQR, inter quartile range.
*Including high dependency units [39].
Unequal variances t-test.
Missing data for G1 and G2, respectively: Type of transportation: 6.1% and 7.0%. Highest level of prehospital care provider: 9.5% and 11.4%. TTA: 0.8% and 0.9%. 30-day mortality: 2.4% and 1.8%. Highest level of inhospital care: 0.9% and 1.0%. Time from alarm to hospital arrival: 17.5% and 19.3%.

Table 5
Sensitivity analysis after excluding patients with significant comorbidity (ASA 3–4) and high age (≥85).

	NISS 9 through 14			NISS 15 through 24			NISS 25 through 75		
	16–64 years, $n = 3390$ (48.5)	≥65 years, $n = 838$ (42.2)	P-value	16–64 years, $n = 2035$ (29)	≥65 years, $n = 691$ (34.8)	P-value	16–64 years, $n = 1572$ (22.5)	≥65 years, $n = 458$ (23)	P-value
Trauma team activation rate, n (%)	3134 (92.8)	668 (79.9)	<0.01	1766 (87.0)	523 (75.8)	<0.01	1413 (90.1)	372 (81.4)	<0.01
30-day mortality, n (%)	≤5	13 (1.6%)	NA	14 (0.7)	9 (1.4)	0.12	154 (10.3)	84 (20.1)	<0.01

Abbreviations: NISS, New Injury Severity Score; NA, not applicable.
Missing data for G1 and G2, respectively: TTA: 0.8% and 0.9%. 30-day mortality: 2.4% and 1.8%.

Fig. 2. This corresponds to findings from a recent study from the German trauma registry [12]. The dominating injury mechanism among geriatric patients was, not surprisingly, low-energy falls (LEF), while for adult patients high-energy falls (HEF) or traffic-related injuries predominated (Fig. 3), comparable to results from other studies [9,45-47]. Relevant diversity existed within the geriatric group (Fig. 3); with increasing age LEFs dominated, but the second most prevalent MOI in Group 2 was HEF (29%), which is found to commonly result from falls from ladders [48]. Other studies more frequently report motor vehicle injuries as the second most frequent MOI [6,45]. Indeed, a second peak of motor vehicle injuries was found in the age group 75–84 years (Fig. 3), reaching almost the same level as age 25–34 years. Traffic-related injuries overall were most prevalent at age 35–44 (44%) while injuries resulting from pedestrian accidents remained stable in all age groups.

Despite the fact that geriatric patients were more often injured by low-energy mechanisms of trauma, we found a larger proportion of patients with NISS≥15 in Group 2 than in Group 1 (G1: 53 vs. G2: 58%, $P<0.01$) (Table 3). Further, the crude mortality was significantly higher (G1: 2.9 vs. G2: 13.6%, $P<0.01$) (Table 3) and the proportion of patients discharged home was significantly lower (G1: 60 vs. G2: 38%, $P<0.01$). The present and previous studies demonstrate that the AIS body regions 'Head' and 'Pelvis and lower extremity' are most frequently severely injured (AIS≥3) in geriatric patients (Fig. 4) [17,45], and traumatic brain injury is associated with high mortality and poor functional outcomes [49]. This, in addition to risk factors of poor outcomes such as age, comorbidities, and use of anticoagulants [52] are factors that may explain some of the observed difference between adult and geriatric patients.

Substantial differences were found in TTA rate between age groups, both when stratified by age and by injury severity. The highest TTA rate (92%) was found in Group 1 patients with NISS 9–14. Comparably, TTA rates from 60 to 72% were found in patients aged 75 years and higher, and geriatric patients had consistently a TTA rate below 80% for all injury severity intervals. A low TTA rate for geriatric patients has been described previously and our results correspond with these findings [19,20,28]. Sensitivity is important for the performance of the triage tool, however, some studies point to other contributing factors for undertriage of geriatric patients than low triage tool sensitivity: Chang et al. studied patients who both met formal triage criteria and was recognized as severely injured by the EMS personnel, yet still they found an undertriage rate to TC of geriatric trauma patients at nearly 50% [50]. A follow-up survey found inadequate training, unfamiliarity with protocol and possible age bias to be important explaining factors [50]. An Australian study by Cox et al. which retrospectively reviewed all trauma patients attended by a state ambulance service between 2007 and 2011 found that despite the triage tool's ability to identify both young and old trauma patients (undertriage rate of 4.5% for older patients), the likelihood of transport to a trauma hospital decreased with increasing age [29]. A Norwegian study reported that if field triage criteria were correctly applied, undertriage in a Norwegian TC could have been reduced from 10.5 to 4.0% [51]. Undertriage of geriatric trauma patients is a complex problem and improvement efforts probably need a multifactorial approach, including educating relevant personnel about the specific characteristics of geriatric trauma and a deeper understanding of the causes of undertriage.

Stratification on pre-specified age-categories was used in analyses to demonstrate clinically relevant heterogeneity in Group 2. The proportion of patients with significant comorbidity (ASA 3–4) and female sex increased with increasing age in our material. Patients 85 years or older and those with significant comorbidity (ASA 3–4) accounted for 47% of Group 2 and were excluded in a sensitivity analysis (Table 5), as these characteristics are associated with increased mortality [52]. The differences between Group 1 and 2 diminished compared to the results from Table 4, although remained statistically significant. Despite having excluded patient with ASA 3–4 and age ≥85 years, the TTA rate of the most severely injured patients (NISS≥25) in Group 2 were almost unchanged. This finding underlines the severe problems in triage of geriatric patients.

Transfer rates to TCs and the proportions of patients receiving definitive care in a TC show less disparity between age groups compared to other variables examined (Table 4). 12% of Group 1 patients with NISS 15–24 were transferred, compared to 8% of Group 2 patients. The proportions receiving care in a TC were 54% in Group 1 and 49% in Group 2 in the same NISS interval. These differences are statistically significant, however clinically they represent a noticeable similarity of in-hospital level of care. The differences in transfer rates were greater for the most severely injured patients (NISS≥25) (G1: 20.6% vs G2: 13.3%, $P<0.01$), and the reason for this may be the poor prognosis associated with high age and very severe injuries [52], where transport and continued care in a TC might be deemed futile. The role of withdrawal of life support and patients' or relatives' own wish to be treated as near home as possible, even if it means not being treated at the recommended specialist facility, needs to be better investigated. Well-designed qualitative studies could probably provide a broader insight of these complex processes.

The similarities in transfer rates and treatment levels between age groups contrasts with the differences in the proportions of patients transported by air ambulance, receiving prehospital physician care, and proportions of patients received by a trauma team. An explanation could be that starting the trauma treatment chain is the crux of geriatric trauma, not merely challenges with the sensitivity of the triage tool. There might be an association between a number of coexisting coincidences: Low-energy trauma does not necessarily attract as much attention as high-energy trauma, geriatric patients might present with no irregular vital signs [25,26], and the patients might have reduced cognitive abilities in conjunction with preexisting conditions or as a consequence of the trauma. In addition, low-energy falls patients can present with low levels of pain complaints and some of them may not call for pre-hospital aid. All this precludes the primary evaluation and make it hard to acknowledge the severity of the injury for both the caller and the dispatch center.

There are both strengths and limitations to this study. First of all, limitations are inherent to the retrospective design, which does not allow for exploration of causal relationships, only associations. To our knowledge this is one of few studies describing epidemiology of geriatric trauma from a uniform national trauma system using data from a national trauma registry with high patient coverage. Although the NTR has a high individual level coverage, mortality calculations are not giving the full picture as not all prehospital deaths are registered. The NTR retrospectively include patients not met by a trauma team with NISS>12. According to the sensitivity of the national triage criteria we were able to include patients with NISS≥9 due to the low threshold for trauma team activation, but patients not meeting inclusion criteria with a NISS between 9 and 12 might be underrepresented in the material. Undertriage, defined as no TTA for patients with Injury Severity Score>15, is a nationally defined benchmark [33], but despite this, only half of Norwegian hospitals identified and reported undertriaged patients [38]. Mainly these are hospitals with small patient volumes and the risk of bias is therefore limited.

Improving patient safety and quality of care for vulnerable groups is one of the central aspects of trauma system development. Comprehensive analyses of the epidemiology of trauma are necessary to ensure that the system is targeted, efficient, safe and responsive to all age groups. As demonstrated in this study, significant differences in characteristics, management and outcome between adult and geriatric patients exist in the Norwegian trauma system. As geriatric trauma incidence rates will continue to increase, improving outcome for this group might be rewarding both for the individual patient and society. Further exploration of the differences in trauma management of adult and geriatric patients is warranted.

Conclusion

In this nationwide study geriatric patients were found to have an increased risk of severe injury, a higher mortality rate, receive less frequently advanced prehospital treatment and transportation and a lower trauma team activation rate, compared to adult patients. Prehospital time was longer for geriatric patients, except for the most severely injured patients. This contrasts to the smaller differences observed in the proportions of patients transferred to trauma centers or receiving definitive care at trauma centers and may reflect true differences in prehospital and in-hospital management of geriatric trauma patients. This is surprising in the setting of a Nordic country with free access to publicly funded emergency services, a nationally implemented trauma system with requirements to pre- and in-hospital services and a national trauma registry with high individual level coverage from all trauma-receiving hospitals. Future research should be directed at providing a deeper understanding of these differences.

Declaration of Competing Interest

The authors declare no competing interests.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2020.11.007.

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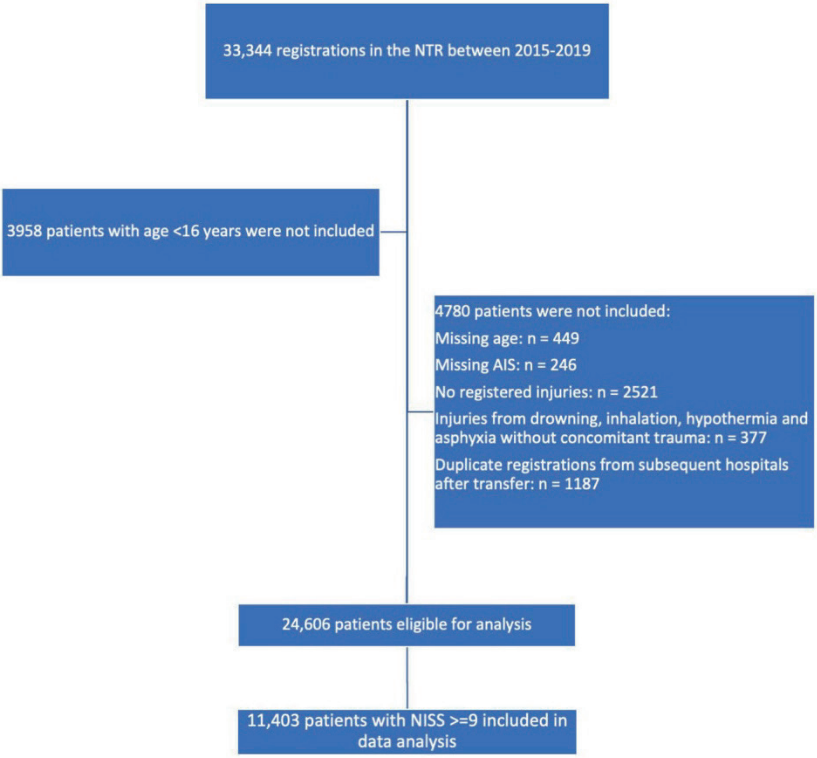
Appendix

Supplemental Online Content

To *Epidemiology of geriatric trauma patients in Norway: A nationwide analysis of Norwegian Trauma Registry data, 2015-2018. A retrospective cohort study*

- Appendix 1: Flowchart of patient inclusion from the Norwegian Trauma Registry
- Appendix 2: Mechanism of injury stratified by age intervals
- Appendix 3: Proportion of patients with severe injuries (AIS ≥3) in various body regions stratified by age.



Appendix 1: Flowchart of patient inclusion from the Norwegian Trauma Registry. Abbreviations: AIS, Abbreviated Injury Scale; NISS, New Injury Severity Score; NTR, Norwegian Trauma Registry.

Appendix 2: Mechanism of injury stratified by age intervals

Age (years)	**16-24**	**25-34**	**35-44**	**45-54**	**55-64**	**65-74**	**75-84**	**85-94**	**≥95**	**16-64**	**≥65**	***P***
Traffic: motor vehicle injury, n (%)	370 (26.3)	243 (19.3)	208 (16.3)	232 (13.2)	222 (12.8)	225 (14.0)	193 (16.9)	60 (7.8)	≤5	17,20 %	13,30 %	<0.01
Traffic: motorcycle injury, n (%)	224 (15.9)	114 (9.1)	143 (11.2)	205 (11.7)	139 (8.0)	46 (2.9)	9 (0.8)	≤5	≤5	11,10 %	1,60 %	<0.01
Traffic: bicycle injury, n (%)	66 (4.7)	126 (10.0)	180 (14.1)	267 (15.2)	269 (15.5)	134 (8.3)	55 (4.8)	10 (1.3)	≤5	12,20 %	5,50 %	<0.01
Traffic: pedestrian, n (%)	48 (3.4)	33 (2.6)	26 (2.0)	45 (2.6)	43 (2.5)	54 (3.4)	47 (4.1)	36 (4.7)	≤5	2,60 %	3,80 %	0,162
Shot by firearm, n (%)	≤5	16 (1.3)	13 (1.0)	12 (0.7)	11 (0.6)	9 (0.6)	≤5	6 (0.8)	≤5	0,80 %	0,40 %	0,0486
Stabbed by sharp object, n (%)	62 (4.4)	100 (7.9)	≤5	56 (3.2)	33 (1.9)	20 (1.2)	6 (0.5)	≤5	≤5	4,20 %	0,80 %	<0.01
Struck or hit by blunt object, n (%)	133 (9.5)	157 (12.5)	174 (13.6)	179 (10.2)	126 (7.2)	79 (4.9)	29 (2.5)	7 (0.9)	≤5	10,30 %	3,20 %	<0.01
Low-energy fall, n (%)	65 (4.6)	66 (5.2)	95 (7.4)	158 (9.0)	292 (16.8)	447 (27.7)	477 (41.8)	462 (60.1)	72 (80.0)	9,10 %	40,40 %	<0.01
High-energy fall, n (%)	351 (25.0)	348 (27.7)	310 (24.3)	526 (30.0)	542 (31.2)	555 (34.5)	301 (26.4)	177 (23.0)	13 (14.4)	28 %	29 %	0,2695
Other, n (%)	82 (5.8)	55 (4.4)	69 (5.4)	73 (4.2)	61 (3.5)	42 (2.6)	24 (2.1)	7 (0.9)	≤5	4,60 %	2,10 %	<0.01
Total (%)	100	100	100	100	100	100	100	100	100	100	100	

Missing data for 16-64 years and ≥65 years, respectively: 3.1% and 3.3%

Appendix 3: Proportion of patients with AIS≥3 injuries in the head, thorax, abdomen, spine, upper ex., and pelvis/lower ex. body region stratified by age

	16-24	25-34	35-44	45-54	55-64	65-74	75-84	85-94	≥95	16-64	≥65	*P*
AIS head ≥3	356 (24.6)	329 (25.2)	318 (24.2)	421 (23.3)	498 (27.8)	543 (32.4)	446 (37.9)	336 (42.6)	33 (36.3)	25.1%	36.4%	<0.01
AIS thorax ≥3	313 (21.6)	305 (23.4)	383 (29.1)	665 (36.8)	639 (35.6)	559 (33.3)	346 (29.4)	176 (22.3)	17 (18.7)	30.1%	29.4%	0.468
AIS abdomen ≥3	210 (14.5)	128 (9.8)	120 (9.1)	139 (7.7)	105 (5.9)	74 (4.4)	44 (3.7)	20 (2.5)	≤5	9.2%	3.8%	<0.01
AIS spine ≥3	123 (8.5)	123 (9.4)	108 (8.2)	165 (9.1)	165 (9.2)	174 (10.4)	105 (8.9)	58 (7.4)	8 (8.8)	8.9%	9.2%	0.58
AIS upper extremity ≥3	30 (2.1)	34 (2.6)	29 (2.2)	41 (2.3)	40 (2.2)	21 (1.3)	15 (1.3)	7 (0.9)	≤5	2.3%	1.2%	<0.01
AIS pelvis and lower extremity ≥3	246 (17.0)	205 (15.7)	177 (13.5)	218 (12.1)	244 (13.6)	243 (14.5)	201 (17.1)	169 (21.4)	28 (30.8)	14.2%	17.2%	<0.01

10.2 Paper II

Differences in time-critical interventions and radiological examinations between adult and older trauma patients: A national register-based study

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BACKGROUND: Older trauma patients are reported to receive lower levels of care than younger adults. Differences in clinical management between adult and older trauma patients hold important information about potential trauma system improvement targets. The aim of this study was to compare prehospital and early in-hospital management of adult and older trauma patients, focusing on time-critical interventions and radiological examinations.

METHODS: Retrospective analysis of the Norwegian Trauma Registry for 2015 through 2018. Trauma patients 16 years or older met by a trauma team and with New Injury Severity Score of 9 or greater were included, dichotomized into age groups 16 years to 64 years and 65 years or older. Prehospital and emergency department clinical management, advanced airway management, chest decompression, and admission radiological examinations was compared between groups applying descriptive statistics and appropriate statistical tests.

RESULTS: There were 9543 patients included, of which 28% (n = 2711) were 65 years or older. Older patients, irrespective of injury severity, were less likely attended by a prehospital doctor/paramedic team (odds ratio [OR], 0.64; 95% confidence interval [CI], 0.57–0.71), conveyed by air ambulance (OR, 0.65; 95% CI, 0.58–0.73), and transported directly to a trauma center (OR, 0.86; 95% CI, 0.79–0.94). Time-critical intervention and primary survey radiological examination rates only differed between age groups among patients with New Injury Severity Score of 25 or greater, showing lower rates for older adults (advanced airway management: OR, 0.60; 95% CI, 0.47–0.76; chest decompression: OR, 0.46; 95% CI, 0.25–0.85; x-ray chest: OR, 0.54; 95% CI, 0.39–0.75; x-ray pelvis: OR, 0.69; 95% CI, 0.57–0.84). However, for the patients attended by a doctor/paramedic team, there were no management differences between age groups.

CONCLUSION: Older trauma patients were less likely to receive advanced prehospital care compared with younger adults. Older patients with very severe injuries received fewer time-critical interventions and radiological examinations. Improved dispatch of doctor/paramedic teams to older adults and assessment of the impact the observed differences have on outcome are future research priorities. (*J Trauma Acute Care Surg.* 2022;93: 503–512. Copyright © 2022 The Author(s). Published by Wolters Kluwer Health, Inc.)

LEVEL OF EVIDENCE: Therapeutic/Care Management; Level III.

KEY WORDS: Trauma; elderly; geriatric; clinical management; prehospital.

The burden of geriatric trauma is expected to increase in correlation with aging populations.[1,2] Compared with younger adults, older people have a two to four times higher risk of death and are more likely to experience reduced functional outcome after severe injury.[3–6] Studies investigating differences in clinical management between age groups have found that older trauma patients receive lower levels of care;[5,7] however, detailed descriptions of prehospital and early in-hospital management with a particular focus on time-critical interventions and radiological examinations are lacking. Exposing management variation in the early phases of trauma care is important for trauma system evaluation and can possibly identify improvement targets.

Airway management and chest decompression (CD) are essential time-critical interventions in trauma management.[8–10] Both interventions are routinely registered in the Norwegian Trauma Registry (NTR)[11] and can be performed basic or advanced reflecting the skills and training of the deployed resources. Chest and pelvic x-rays are part of the primary survey according to the Norwegian adaptation of the Advanced Trauma Life Support (ATLS) guidelines.[10] Chest x-ray is one of the earliest checkpoints in the primary survey, serving as a marker of the acuity of care given.[10]

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Extracts of this study were presented at the 2021 annual meetings for the Norwegian Society of Anaesthesiology and the Norwegian Orthopaedic Association.

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Previous studies have shown that older adults benefit from improvement of existing trauma system practices.[12] Differences in clinical management in disfavor of older patients must be given attention as a possible trauma system improvement opportunity. The aim of this study was to compare prehospital and in-hospital clinical management of adult and older trauma patients, focusing on time-critical interventions and radiological examinations.

MATERIALS AND METHODS

Study Design and Setting

This study conforms with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines and a complete checklist has been uploaded as Supplemental Digital Content (Supplementary Material 1, http://links.lww.com/TA/C347).[13] In line with the protocol for the study,[14] we performed a retrospective cohort study of all trauma cases in Norway meeting inclusion criteria, between January 1, 2015, and December 31, 2018. Data were extracted from the NTR.

Norway has a population of 5.4 million people, of which approximately 16.5% are 65 years or older.[15] The health care system is publicly funded, and a nationwide inclusive trauma system is implemented, describing national field triage criteria (Fig. 1) and uniform requirements to all prehospital services and hospitals.[16] Clinical management of severely injured patients in Norway follow an adaptation of the Prehospital Trauma Life Support and ATLS guidelines incorporated in the national trauma plan.[16] Trauma patients are managed in trauma centers (TCs) or acute care trauma hospitals (ACTHs) equivalent to American College of Surgeons Committee on Trauma Level I or Level II and Level III TC, respectively.[17] All ACTH and TC have 24/7 trauma team availability led by an ATLS educated experienced resident or a surgical consultant. Calls made to the national medical emergency

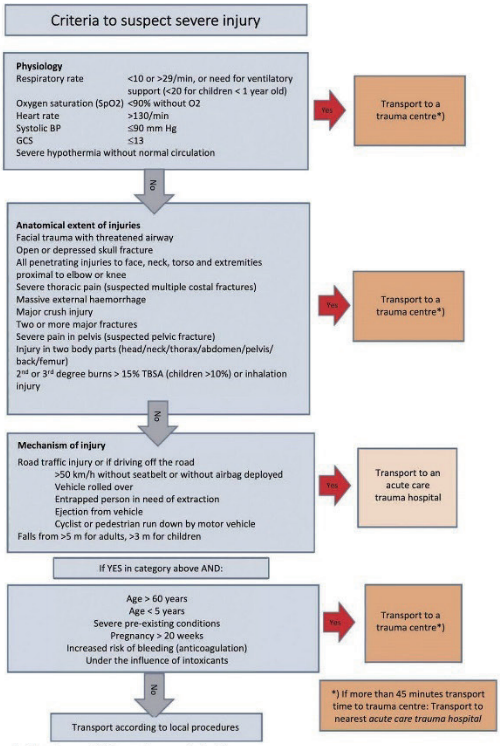

Figure 1. National criteria for field triage of injured people in Norway.

number (113) are evaluated by specially trained emergency medical dispatch center (EMDC) personnel using the "Norwegian Index for Medical Emergencies" (Index), a criteria-based system for dispatch of emergency medical service resources.[18] The national trauma field triage criteria are incorporated in the injury chapters. The EMDC operator controls ground ambulance dispatch. Ground ambulances are mainly staffed by emergency medical technicians, paramedics, or nurses. Doctor/paramedic teams are available in a nationwide network. These are manned by an anesthesiologist and a rescue paramedic/nurse, which deploy by helicopter or rapid response cars. No national criteria for doctor/paramedic team dispatch exists.[19,20] In all Index chapters, doctor/paramedic team dispatch is suggested for conditions qualifying for the most urgent response. The EMDC operator must recognize a possible need for advanced prehospital care or air transport and involve the on-call prehospital physician.[20] All emergency medical services deliver basic interventions (simple airway maneuvers and pharyngeal airways, needle CD), while advanced interventions (advanced airway management [AAM]: supraglottic airway devices, endotracheal intubation/prehospital anesthesia and surgical airway, and chest thoracostomy) are reserved doctor/paramedic teams.

Selection of Participants

In the study period, four TC and 34 ACTH delivered data to the NTR. The NTR holds information about patients who meet the following inclusion criteria: Admitted through trauma team activation (TTA), admitted without TTA but found to have penetrating injuries to head, neck, torso, or extremities proximal to knee or elbow, head injury with Abbreviated Injury Scale (AIS) score of 3 or higher, or New Injury Severity Score (NISS) greater than 12.[21] Of patients received by a trauma team, a high coverage is achieved (>95%).[21]

A total of 33,344 patients were registered in the NTR between 2015 and 2019. Only patients met by a trauma team that were 16 years or older and with NISS ≥9 were included. Patients with missing information about age or AIS or with injuries from drowning, inhalation, hypothermia, and asphyxia without concomitant trauma were excluded (Supplemental Digital Content, Supplementary Fig. 1, http://links.lww.com/TA/C348).

Data Collection and Management

Data collection is based on the Utstein template and includes data from all parts of the treatment chain, from accident site to rehabilitation.[11] The NTR's status as a national quality registry has warranted mandatory data delivery since 2006, regulated by law since 2019.[22] All patients are registered with a waiver of consent. Injuries are coded according to the AIS manual 2005 version, update 2008[23] by certified nurse registrars. The AIS and NISS measure injury severity.[24]

The study population was dichotomized by age into "group 1" (G1) aged 16 years to 64 years and "group 2" (G2) 65 years and older. Prespecified subcategories were defined as age intervals 65 years to 74 years, 75 years to 84 years, and 85 years or older.[14] According to the AIS severity description, NISS was grouped into intervals 9 to 14, 15 to 24, and 25 or higher.[23] For patients with multiple injuries in the same body region, only the most severe was included in analyses concerning body regions with severe injuries (AIS score, ≥ 3). Glasgow Coma Scale (GCS) was categorized according to Head Injury Severity Scale (HISS).[25] Preinjury physical status was defined by the American Society of Anesthesiologists physical status classification system (ASA-PS).[26,27] Abbreviated Injury Scale codes for major pneumothorax, tension pneumothorax, hemothorax, and hemopneumothorax (all with AIS severity designation 3–5) were used to assess indication for CD between groups.[23]

Place of injury is registered as the public municipality number where the injury occurred and is mapped to the Centrality Index of Norway, a continuous variable developed by Statistics Norway grouped into six categories, from highest (1) to lowest (6) centrality.[28] Categories 1 through 4 were merged to "Urban Norway" and remaining categories "Remote Norway." For time analyses, outliers were excluded based on data distribution and insight from clinical practice: For "Prehospital time," outliers longer than 24 hours were excluded (0.1%) in line with the Utstein template.[11] For "Time from admission to x-ray chest," outliers longer than 90 minutes were excluded (1.6%). For "Time from admission to computed tomography (CT)" outliers less than 10 minutes (0.7%) and longer than 90 min (2.7%) were excluded. A complete list of variables collected from NTR and details about recategorization of selected variables are found as Supplemental Digital Content, Supplementary Material 2 (http://links.lww.com/TA/C349).

Each registry score component has a category for "unknown" information, which was analyzed as "missing." All variables had 5% missing data or less, except from "prehospital GCS" (17%), "highest level of prehospital care provider" (7%), "time from alarm to hospital arrival" (15%), "emergency department (ED) GCS" (9%), "time from hospital arrival to x-ray chest" (15%), and "Time from hospital arrival to CT" (20%). Details are provided in the tables. No imputation was performed.

Statistics

Continuous data are presented as means with standard deviations (SDs) or medians with interquartile ranges (IQR) and categorical data are reported as numbers and proportions. For continuous data, differences between age groups were evaluated using independent samples t test, unequal variances t test, and Mann-Whitney U test, as appropriate. For categorical data, Pearson's χ^2 test or Fisher's exact test were used, and effect size estimated with odds ratios (ORs) with 95% confidence intervals (CIs). A p value less than 0.05 (two-tailed) was considered to indicate significance. Analyses were performed using SPSS v.27 (IBM Corp., Armonk, NY).

Ethics

All patients receive written information about the registry, including the opportunity to access the data recorded and to deny registration. Deidentified data were extracted. Variables with information about five or less patients are not reported, in line with Norwegian data protection standards. The study was approved by the Oslo University Hospital data protection officer (no. 19/16593).

RESULTS

Characteristics of Study Objects

A total of 9543 patients met the inclusion criteria (Supplemental Digital Content, Supplementary Fig. 1, http://links.lww.com/TA/C348), of which 72% were 16 years to 64 years of age

(G1) and 28% were 65 years or older (G2). The median age in G1 was 42 years (IQR, 28–53) and 75 years (IQR, 69–82) in G2. Study population demographics, injury characteristics, and outcomes stratified by age are listed in Table 1. Male sex predominated in both groups, although the female proportion increased with increasing age. Patients in G2 had a higher median ASA-PS score ($p < 0.001$), with 31% classified as ASA-PS 3 or higher, as opposed to 5% in G1 ($p < 0.001$). Blunt trauma constituted 95% in the study cohort. In G1, traffic-related injuries (TRIs) (46%) and high-energy falls (HEFs) (28%) dominated, while in G2 HEF were most frequent (33%), over TRI (31%), and low-energy falls (LEFs) (28%). The ASA-PS score was significantly higher among G2 patients injured by LEF compared with HEF (ASA-PS ≥ 3: LEF: n = 380 (51.6%); HEF: n = 238 (27.6%), $p < 0.001$). A higher proportion of patients with NISS of 15 or greater was observed in G2 ($p < 0.001$). G2 had a higher proportion of severe injuries in AIS body regions Head and Thorax (AIS score ≥ 3), while severe abdominal injuries were more frequent in G1. No difference was seen in the pelvis or lower extremity body region. Moreover, G2 had a higher rate of severe head injuries (AIS head score ≥ 3) through all NISS intervals (NISS, 9–14: G1, n = 232 (7.0%) vs. G2, n = 109 (9.8%); NISS, 15–24: G1, n = 451 (23.7%) vs. G2, n = 281 (32.7%); NISS, ≥ 25: G1, n = 906 (56.8%) vs. G2, n = 529 (71.9%); all $p < 0.01$). G1 and G2 had similar distributions of urban and remote injury locations. Crude 30-day mortality was 3.0% and 14.8% in G1 and G2, respectively ($p < 0.001$).

Prehospital GCS and Clinical Management

Prehospital GCS was significantly lower in G2 compared with G1, demonstrated by the higher proportions of patients in G2 with GCS less than 9 and less than 14 ($p < 0.001$) (Table 2). The overall prehospital AAM rate was 6.8% in G1 and 5.5% in G2 ($p = 0.02$) (Table 2). Approximately 85% of patients receiving AAM had their tracheas intubated and 15% received supraglottic airway device or other, showing no significant difference between groups ($p = 0.47$). Prehospital doctor/paramedic team attendance and air ambulance transportation increased with increasing injury severity for both groups, although these were observed significantly less frequently in G2, both in the entire cohort, in the subgroup of patients with GCS score less than 9, and across all injury severity subgroups (Table 2, Supplemental Digital Content, Supplementary Table 1, http://links.lww.com/TA/C350). Among patients attended by a doctor/paramedic team, no significant differences between age groups were observed for AAM, both overall and adjusted for GCS score less than 9 and NISS of 25 or greater. Further,

TABLE 1. Study Population Demographics, Injury Characteristics and Outcome Stratified by Age

	G1: 16–64 y, n = 6832 (72%)	G2: ≥65 y, n = 2711 (28%)	p	65–74 y, n = 1353 (50%)	75–84 y, n = 836 (31%)	≥85 y, n = 522 (19%)
Age: median (IQR), y	42 (28–53)	75 (69–82)	NP	69 (67–72)	79 (76–82)	89 (86–92)
Male sex, n (%)	5294 (77.5)	1783 (65.8)	<0.001	1010 (74.6)	533 (63.8)	240 (46.0)
Preinjury ASA-PS[a], median (IQR)	1 (1–2)	2 (1–3)	<0.001*	2 (1–2)	2 (2–3)	3 (2–3)
ASA-PS 1, n (%)	4710 (70.6)	665 (25.1)		462 (35.1)	165 (20.1)	38 (7.4)
ASA-PS 2, n (%)	1603 (24.0)	1152 (43.5)	<0.001	556 (42.2)	380 (46.4)	216 (42.0)
ASA-PS 3**, n (%)	357 (5.4)	833 (31.4)		299 (22.7)	274 (33.5)	260 (50.6)
Place of injury[b], n (%)						
Urban Norway	5466 (83.3)	2192 (83.0)	0.75	1064 (81.3)	678 (82.8)	450 (87.5)
Remote Norway	1098 (16.7)	449 (17.0)		244 (18.7)	141 (17.2)	64 (12.5)
Dominating injury type[c], n (%)						
Blunt	6322 (94.0)	2613 (97.8)	<0.001	1291 (97.1)	817 (98.8)	505 (97.7)
Penetrating	405 (6.0)	60 (2.2)		38 (2.9)	10 (1.2)	12 (2.3)
Mechanism of injury[d]						
Transport-related	3052 (45.7)	830 (31.3)		441 (33.5)	283 (34.5)	106 (20.7)
Low-energy fall	439 (6.6)	747 (28.2)	<0.001	264 (20.0)	242 (29.5)	241 (47.1)
High-energy fall	1856 (27.8)	865 (32.6)		478 (36.3)	243 (29.6)	144 (28.1)
Other	1336 (20.0)	208 (7.8)		135 (10.2)	52 (6.3)	21 (4.1)
NISS, median (IQR)	17 (12–22)	17 (12–26)	<0.001**	17 (12–26)	17 (12–27)	17 (12–27)
9–14	3334 (48.8)	1115 (41.1)		562 (41.5)	330 (39.5)	223 (42.7)
15–24	1904 (27.9)	860 (31.7)	<0.001	440 (32.5)	277 (33.1)	143 (27.4)
≥25	1594 (23.3)	736 (27.1)		351 (25.9)	229 (27.4)	156 (29.9)
AIS score ≥ 3, n (%)						
Head	1614 (23.7)	921 (34.1)	<0.001	407 (30.2)	301 (36.0)	213 (40.9)
Thorax	2055 (30.2)	892 (33.0)	0.007	478 (35.5)	275 (32.9)	139 (26.7)
Abdomen	629 (9.2)	119 (4.4)	<0.001	62 (4.6)	38 (4.6)	19 (3.6)
Lower extremity/pelvis	978 (14.4)	357 (13.2)	0.145	167 (12.4)	111 (13.3)	79 (15.2)
30-d mortality[e], n (%)	202 (3.0)	394 (14.8)	<0.001	87 (6.6)	137 (16.7)	170 (32.9)

Missing data for G1 and G2, respectively: a: 2.4% and 2.3%. b: 3.9% and 2.6%. c: 1.5% and 1.4%. d: 2.2% and 2.3%. e: 2.1% and 1.6%.
*Mann-Whitney *U* test.
**Includes 17 (G1) and 62 (G2) patients with ASA 4. No patients with ASA 5 or 6.
NP, not performed.

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TABLE 2. Prehospital GCS, Clinical Management, and Time-Critical Interventions Stratified by Age

	G1: 16–64 y, n = 6832 (72%)	G2: ≥65 y, n = 2711 (28%)	p/OR With 95% CI	65–74 y, n = 1353 (50%)	75–84 y, n = 836 (31%)	≥85 y, n = 522 (19%)
GCS score[a], median (IQR)	15 (14–15)	15 (14–15)	<0.001*	15 (14–15)	15 (13–15)	15 (12–15)
GCS score < 9, n (%)	575 (10.1)	246 (11.1)		109 (9.9)	80 (11.6)	57 (13.4)
GCS score 9–13, n (%)	548 (9.6)	305 (13.8)	<0.001	131 (11.9)	96 (13.9)	78 (18.4)
GCS score 14–15, n (%)	4566 (80.3)	1667 (75.2)		863 (78.2)	515 (74.5)	289 (68.2)
Highest level of prehospital care provider[b], n (%)						
Physician	2032 (31.9)	580 (23.0)	0.64 (0.57–0.71)	328 (26.2)	184 (23.8)	68 (13.8)
Ambulance personnel or other**	4341 (68.1)	1940 (77.0)		924 (73.8)	590 (76.2)	426 (86.2)
Physician attendance						
If GCS score < 9	332 (58.3)	110 (45.1)	0.59 (0.43–0.79)	53 (48.6)	40 (51.3)	17 (29.8)
If NISS ≥ 15	1330 (40.9)	405 (27.3)	0.54 (0.47–0.62)	234 (31.6)	128 (27.7)	43 (15.3)
AAM[c], n (%)	444 (6.8)	143 (5.5)	0.80 (0.66–0.97)	76 (5.9)	44 (5.4)	23 (4.5)
AAM in patients with GCS score < 9, n (%)	305 (53.4)	101 (41.2)	0.61 (0.45–0.83)	51 (46.8)	32 (40.5)	18 (31.6)
Chest decompression[d], n (%)	69 (1.1)	20 (0.8)	0.72 (0.44–1.19)	13 (1.0)	NA†	NA†
Type of transportation[e], n (%)						
Air ambulance	1558 (23.9)	436 (17.0)	0.65 (0.58–0.73)	254 (19.8)	143 (18.1)	39 (7.8)
Ground ambulance or other‡	4957 (76.1)	2136 (83.0)		1029 (80.2)	648 (81.9)	459 (92.2)
Air ambulance transportation, n (%)						
If GCS score < 9	211 (37.0)	66 (26.9)	0.63 (0.45–0.88)	32 (29.4)	26 (32.5)	8 (14.0)
If NISS ≥ 15	1023 (30.9)	303 (20.2)	0.57 (0.49–0.65)	182 (24.3)	99 (21.1)	22 (7.8)
Primary destination[f]						
Trauma Center, n (%)	2980 (43.6)	1083 (39.9)	0.86 (0.79–0.94)	547 (40.4)	325 (38.9)	211 (40.4)
Acute Care Trauma Hospital, n (%)	3852 (56.4)	1628 (60.1)		806 (59.6)	511 (61.1)	311 (59.6)
Prehospital time[g]: median (IQR), min	64 (38–99)	68 (44–105)	NP	68 (45–105)	69 (43–107)	66.5 (44–102)
Mean (SD), min	79 (72)	89 (89)	<0.001§	90 (91)	89 (87)	88 (87)

Missing data for G1 and G2, respectively: a: 17% and 18%. b: 7% and 7%. c: 4% and 3%. d: 4% and 3%. e: 5% and 5%. f: 0%. g: 15% and 16%.
*Mann-Whitney *U* test.
**"Other" includes 65 (G1) and 12 (G2) patients.
†NA: not reported due to low patient numbers.
‡"Other" includes 197 (G1) and 59 (G2) patients.
§Unequal variances *t* test.
NA, not applicable; NP, not performed.

no significant differences were observed for CD and direct TC transport. Clinical management of patients attended by a prehospital physician is displayed in Table 3.

Significant difference in AAM rate between G1 and G2 was only observed in the NISS of 25 or greater subgroup (G1, 22.0%; G2, 14.4%; OR, 0.60; 95% CI, 0.47–0.68). As expected, the highest proportions were observed in the subgroup of patients with NISS of 25 or greater and GCS score less than 9, however, at significantly lower rates for G2 (G1, 62.2%; G2, 44.1%; OR, 0.48; 95% CI, 0.33–0.68) (Supplemental Digital Content, Supplementary Table 1, http://links.lww.com/TA/C350). Prehospital CD was performed in approximately 1% of all patients and

TABLE 3. Emergency Interventions and Transport Destination in the Subgroup of Patients Attended by a Prehospital Physician

	G1: 16–64 y, n = 2032 (78%)	G2: ≥65 y, n = 580 (22%)	OR With 95% CI	65–74 y, n = 328 (56%)	75–84 y, n = 184 (32%)	≥85 y, n = 68 (12%)
AAM[a], n (%)	384 (18.9)	122 (21.1)	1.15 (0.91–1.44)	66 (20.2)	38 (20.8)	18 (26.5)
In patients with GCS < 9[b]	261 (78.6)	84 (76.4)	0.88 (0.53–1.47)	42 (79.2)	29 (72.5)	13 (76.5)
In patients with NISS ≥ 25	304 (41.0)	90 (41.7)	1.03 (0.76–1.40)	46 (39.7)	31 (41.9)	13 (50.0)
Chest decompression[c], n (%)	62 (3.1)	15 (2.6)	0.84 (0.45–1.50)	9 (2.8)	NA*	NA*
In patients with NISS ≥ 25	53 (7.1)	10 (4.6)	0.63 (0.32–1.26)	6 (5.2)	NA*	NA*
Primary destination[d], n (%)						
Trauma Center	1225 (60.3)	325 (56.0)	0.84 (0.70–1.01)	144 (43.9)	78 (42.4)	33 (48.5)
Acute Care Trauma Hospital	807 (39.7)	255 (44.0)		184 (56.1)	106 (57.6)	35 (51.5)

Missing data for G1 and G2, respectively: a: 0.2% and 0.3%; b (GCS missing): 9.4% and 9.5%; c: 0.2% and 0.3%; d: 0%.
*NA: not reported due to low patient numbers.
NA, not applicable.

significant differences between age groups were only observed in the NISS of 25 or greater subgroup (G1, 3.9%; G2, 1.8%; OR, 0.46; 95% CI, 0.25–0.85) (Supplemental Digital Content, Supplementary Table 1, http://links.lww.com/TA/C350). Of the 89 patients receiving prehospital CD, 50 received a chest drain (56%), 21 needle decompression (24%), 13 an incision (15%), and five other or unknown (6%). Indication for CD, defined as relevant AIS codes previously described, did not differ between age groups (G1, n = 483 (7.1%); G2, n = 213 (7.9%); $p = 0.182$).

Mean time from alarm to hospital arrival was 79 minutes in G1 and 89 minutes in G2 ($p < 0.001$). G2 patients were less frequently transported to a TC as primary destination (G1, 43.6%; G2, 39.9%; OR, 0.86; 95% CI, 0.79–0.94).

ED Physiologic Variables and Clinical Management

Emergency department GCS was significantly lower in G2 than G1 among patients with NISS of 15 or greater ($p = 0.004$), demonstrated by the higher proportions of patients with ED GCS score less than 9 and less than 14 (NISS, 15–24: $p = 0.03$; NISS, ≥ 25: $p = 0.006$) (Table 4). The proportion of patients with systolic blood pressure (SBP) less than 90 mm Hg was higher in G2, except in the NISS of 25 or greater subgroup where the groups were similar. Emergency department physiologic parameters and clinical management are displayed in Table 4.

Overall, ED intubation rates were 8.8% and 8.0% in G1 and G2, respectively ($p = 0.43$) (Supplemental Digital Content, Supplementary Table 2, http://links.lww.com/TA/C351). Among patients with NISS less than 25, no significant differences in intubation rates or chest drain insertion rates were observed (Table 4). Among patients with NISS of 25 or greater, G2 patients were less frequently intubated or received chest drain (intubation: G1, 22.5%; G2, 17.8%; OR, 0.75; 95% CI, 0.60–0.93; chest drain: G1, 23.5%; G2, 15.7%; OR, 0.61; 95% CI, 0.48–0.78) (Table 4).

ED Radiological Examinations

X-ray of the chest was performed in more than 90% of patients across age and injury severity groups (Table 5, Supplemental Digital Content, Supplementary Table 3, http://links.lww.com/TA/C352). The median time was 5 minutes from hospital admission (Table 5). X-ray of the pelvis were performed in 71% to 78% of patients, with lowest rates observed for older adults with NISS of 25 or greater (NISS, ≥25: G1, 78.2%; G2, 71.2%; OR, 0.69; 95% CI, 0.57–0.84; Table 4). Emergency department CT was performed in 87% to 90% of patients through both age groups and all injury severity groups with no significant differences observed (Table 5). Among patients with severe injuries (AIS score ≥ 3) in the thorax or the pelvis and lower extremity, G2 patients less frequently received x-ray of the chest and pelvis on admission (thorax, $p = 0.001$; pelvis and lower extremity, $p = 0.031$) (Supplemental Digital Content, Supplementary Table 4, http://links.lww.com/TA/C353).

DISCUSSION

The aim of this study was to compare clinical management of adult and older trauma patients, focusing on prehospital and early in-hospital time-critical interventions and admission

TABLE 4. Emergency Department Physiologic Parameters and Clinical Management Stratified by NISS and Age

	NISS 9 Through 14			NISS 15 Through 24			NISS 25 Through 75		
	G1: 16–64 y, n = 3334 (49%)	G2: ≥65 y, n = 1115 (41%)	p/OR With 95% CI	G1: 16–64 y, n = 1904 (28%)	G2: ≥65 y, n = 860 (32%)	p/OR With 95% CI	G1: 16–64 y, n = 1594 (23%)	G2: ≥65 y, n = 736 (27%)	p/OR With 95% CI
GCS[a], median (IQR)	15 (15–15)	15 (15–15)	0.11*	15 (15–15)	15 (14–15)	0.004*	14 (10–15)	14 (9–15)	0.004*
GCS score <9, n (%)	68 (2.1)	17 (1.6)		52 (2.9)	29 (3.7)		287 (22.5)	151 (24.9)	
GCS score 9–13, n (%)	163 (5.1)	71 (6.7)	0.086	138 (7.8)	85 (10.7)	0.03	205 (16.1)	127 (21.0)	0.006
GCS 14–15, n (%)	2975 (92.8)	974 (91.7)		1578 (89.3)	680 (85.6)		783 (61.4)	328 (54.1)	
SBP[b]: mean (SD), mm Hg	136.5 (20.7)	146.4 (29.3)	<0.001**	133.2 (21.3)	143.2 (28.3)	<0.001**	126.7 (29.5)	141.3 (35.4)	<0.001**
<90 mm Hg, n (%)	44 (1.3)	36 (3.3)	<0.001	39 (2.1)	35 (4.1)	0.002	153 (9.9)	57 (8.0)	0.15
Endotracheal intubation[c], n (%)	120 (3.6)	37 (3.3)	0.92 (0.63–1.34)	124 (6.5)	50 (5.8)	0.89 (0.63–1.24)	359 (22.5)	131 (17.8)	0.75 (0.60–0.93)
If ED GCS < 9, n (%)	27 (39.7)	9 (52.9)	1.71 (0.59–4.98)	28 (53.8)	13 (44.8)	0.70 (0.28–1.74)	149 (51.9)	71 (47.0)	0.82 (0.55–1.22)
ED chest drain[d], n (%)	99 (3.0)	37 (3.4)	1.13 (0.77–1.66)	144 (7.7)	59 (7.0)	0.90 (0.66–1.23)	316 (23.5)	102 (15.7)	0.61 (0.48–0.78)

*Mann-Whitney *U* test.
**Unequal variances *t* test.
Missing data by increasing NISS interval for G1 and G2, respectively: a: 4%, 7%, 20% and 5%, 8%, 18%; b: 1%, 1%, 4% and 1%, 1%, 3%; c: 0%; d: 1%, 2%, 16% and 2%, 2%, 12%.

TABLE 5. Emergency Department Radiological Examinations Stratified by NISS and Age

	NISS 9 Through 14			NISS 15 Through 24			NISS 25 Through 75		
	G1: 16–64 y, n = 3334 (49%)	G2: ≥65 y, n = 1115 (41%)	p/OR With 95% CI	G1: 16–64 y, n = 1904 (28%)	G2: ≥65 Years, n = 860 (32%)	p/OR With 95% CI	G1: 16–64 y, n = 1594 (23%)	G2: ≥65 y, n = 736 (27%)	p/OR With 95% CI
X-ray chest[a], n (%)	3014 (90.5)	1021 (91.7)	1.16 (0.91–1.47)	1774 (93.2)	784 (91.2)	0.76 (0.56–1.02)	1505 (94.5)	665 (90.4)	0.54 (0.39–0.75)
X-ray pelvis[b], n (%)	2541 (76.4)	854 (76.9)	1.03 (0.88–1.21)	1482 (78.0)	651 (76.0)	0.89 (0.74–1.08)	1242 (78.2)	523 (71.2)	0.69 (0.57–0.84)
CT[c], n (%)	2929 (87.9)	998 (89.7)	1.2 (0.96–1.49)	1745 (91.7)	778 (90.6)	0.86 (0.65–1.15)	1399 (87.8)	665 (90.4)	1.30 (0.98–1.73)
Time to x-ray chest[d]: median (IQR), min	5 (3–9)	5 (4–9)	NP	5 (3–8)	5 (3–8)	NP	5 (3–8)	5 (3–8)	NP
Mean (SD)	7.9 (9.6)	8.9 (11.5)	0.009*	7.2 (8.3)	7.6 (9.4)	0.42*	6.4 (6.5)	7.5 (9.7)	0.006*
Within 15 min (%)	91.4	89.2	NP	93.0	92.2	NP	95.5	93.5	NP
Within 60 min (%)	99.1	98.6	NP	99.4	98.9	NP	99.7	99	NP
Time to CT[e], median (IQR), min	30 (22–40)	30 (24–40)	NP	30 (22–39)	30 (23–40)	NP	26 (20–37)	27 (21–38)	NP
Mean (SD)	32.9 (14.6)	33.3 (13.9)	0.50*	32.6 (14.4)	34.4 (16.3)	0.01*	30.7 (14.6)	30.8 (14.4)	0.87*

Missing data by increasing NISS interval for G1 and G2, respectively: a: 0%; b: 0%; c: 0%; d: 12%, 15%, 21% and 15%, 17%, 17%; e: 23%, 20%, 24% and 24%, 21%, 24%.
*Independent-sample t test.
NP, not performed.

radiological examinations. Findings showed that, irrespective of injury severity, older patients (≥65 years) received lower rates of prehospital doctor/paramedic team attendance, air ambulance conveyance, and transport directly to a TC. Severely injured older patients (NISS ≥ 25) received prehospital and in-hospital AAM and CD, and primary survey x-ray imaging significantly less frequently than younger adults. We found no significant differences in AAM and CD rates in patients managed by prehospital doctor/paramedic teams. No significant differences in time-critical interventions or radiological examinations were observed among patients with moderate to severe injuries (NISS < 25).

The study population demographics and injury characteristics are in line with previous comparable studies: older adults were more often female, had significant comorbidity, more than 30% had at least one severe head injury, a higher proportion had GCS score less than 9, and mortality was higher (Table 1).[4,5,29,30] Noticeably, HEFs and traffic-related injuries were the most common injury mechanisms among older patients. Other studies describe a surge of LEFs in the older population,[4,5,29,30] similar to findings in a Norwegian study.[31] However, the present study excluded all those not met by a trauma team to enable within-system evaluation of clinical management. This highlights that TTA is still strongly linked to high-energy mechanisms of trauma even for older adults,[32,33] despite several publications and ATLS curriculum emphasizing the high risk of severe injuries from LEFs in the elderly.[10,34] Additionally, important clinical characteristics warranting high-level care and expedite transport were equally or more frequently present in G2 than in G1, such as higher proportions of patients with AIS head score of 3 or higher, GCS score less than 9, NISS of 15 or greater, or significant comorbidity (Table 1, Table 2). This was not reflected in the prehospital management, where elderly patients were less often attended by a prehospital doctor/paramedic team, conveyed by air ambulance, or transported to TC as primary destination (Table 2, Supplemental Digital Content, Supplementary Table 1, http://links.lww.com/TA/C350). Inadequate activation of the trauma system is the challenge, beginning with dispatch.

Elderly patients are frequently injured by insignificant trauma mechanisms and present with vague symptoms.[31,35,36] This increases the risk for the EMDC operator to not recognize or underestimate injury severity, leading to application of nontrauma-specific operative chapters in the Index. This may be one of the reasons why we observed lower rates of doctor/paramedic team attendance, air ambulance conveyance and subsequently prehospital time-critical interventions. A study of all trauma-related emergency calls in South-Eastern Norway reported that operative chapters in the Index containing trauma-specific information was used in 88% of calls,[19] suggesting an area for improvement.

The Norwegian criteria for trauma field triage share design characteristics and specific criteria with triage tools associated with undertriage of older patients (Fig. 1).[37,38] By design, the Index recommends involving doctor/paramedic teams when patients match field triage criteria (Fig. 1), which older injured patients are less likely to do.[35–37] In this study, younger adults showed a mechanism of injury distribution more likely to meet field triage criteria (TRI, HEF, and other), which may have contributed to the higher frequency of doctor/paramedic team attendance and air ambulance conveyance for G1 (Table 1). On the other hand, being older than 60 years, advanced comorbidity, and use of anticoagulants are criteria that lower the threshold for transport to a TC and TTA (Fig. 1). This could have influenced decision to dispatch advanced doctor/paramedic teams to more older adults, although the extent is uncertain as information about comorbidity and medication is not easily accessible for EMDC and prehospital personnel. Geographic location did not significantly differ between the groups and is, therefore, unlikely to have contributed to differences. Besides the convincing evidence that elderly in this study had lower prehospital GCS and, therefore, signs of physiologic derangement, we cannot further assess the influence of physiologic criteria on dispatch differences due to the levels of missing data on other variables (SBP, respiratory rate).

Differences in clinical management, must be given attention as possible improvement targets. We find EMDC triage and dispatch to be the crux of trauma system activation and suggest improvements: first, the Index should better guide operators in injury assessment of elderly, e.g., explicit information about likelihood of severe injuries despite low-energy trauma, and a reminder to consider trauma in acutely unwell elderly patients could be placed in the chapter *Unidentified Problem*. Second, our findings reveal a need to redefine trauma criteria, especially for elderly patients. This is a matter of great interest internationally, and this includes surveillance of literature and implementation of changes if justified. A recent systematic review of elderly-specific triage criteria found no studies that could demonstrate undertriage levels below the 5% recommended by American College of Surgeons Committee on Trauma.[17,37] Third, use of video assisted EMDC triage, recently deployed at most EMDCs in Norway, should be encouraged and assessed according to dispatch precision. Smaller studies show promising results where it is reported to be particularly helpful in situations where no trigger for instant dispatch was met, typically for LEFs.[39] Finally, continued efforts to educate personnel in the specific challenges relating to older trauma patients should be a priority for all parts of the trauma treatment chain.

Prehospital time-critical interventions are closely linked to the dispatch of doctor/paramedic teams (Table 2, Table 3). Both G1 and G2 received AAM and CDs at similar rates when attended by a doctor/paramedic team. Griggs et al.[40] recently showed that doctor/paramedic team involvement in older trauma patients frequently led to time-critical interventions, particularly prehospital anesthesia and intubation, even among patients with low-energy trauma who did not fulfill the initial criteria for immediate dispatch. This supports our finding that physicians on scene perform advanced interventions also at high age, although likely from a careful selection of cases. To what extent advanced prehospital care and bypass to TC care is beneficial for older adults should be investigated in future studies, as well as the effect changes in dispatch criteria have on dispatch of advanced resources to elderly, the frequency of interventions, and association with outcome.

The key findings from our comparisons of inhospital care were that no significant differences in time-critical interventions or radiological examinations were observed among patients with NISS less than 25, and the median time from hospital admission to chest x-ray was 5 minutes across age groups and injury severity subgroups (Table 4, Supplemental Digital Content, Supplementary Table 3, http://links.lww.com/TA/C352). This shows that the Norwegian trauma system is efficient and responsive for all admitted adult patients. Older patients with NISS of 25 or greater, however, less frequently received prehospital and ED AAM, CD, and admission x-ray imaging (Table 4, Table 5, Supplemental Digital Content, Supplementary Tables 1, http://links.lww.com/TA/C350 and 3, http://links.lww.com/TA/C352). Age and injury severity are known risk factors for a poor prognosis after trauma[41] and in line with previous research, our findings show how both are associated with decreasing intervention and examination rates.[42] Consequently, the differences in clinical management observed among patients in the highest NISS subgroup (≥25) may be based on sound clinical risk-benefit evaluations leading to limitations or withdrawal of aggressive care where deemed futile or where advance care directives were placed. Unfortunately, this cannot be evaluated based on our data. As injury mechanism and preexisting medical conditions differ between age groups, it would be expected that care given will vary as well.

One of this study's strengths are the analyses of data from all trauma hospitals in a country where a national inclusive trauma system is implemented. Similarities shared between Norway's and other countries' inclusive trauma systems make the findings transferable. There are some limitations to our study, first and foremost related to its retrospective design. We relied on AIS, NISS, and GCS score less than 9 to determine injury severity, although we appreciate that more data about vital signs would bring valuable information. This was not available because of incomplete registration of prehospital data, a challenge for many registries and services.[43] The indication for performing or not performing time-critical interventions is not registered in the NTR. Instead, we used measures with a high likelihood of indication for interventions, such as injury stratification and GCS score less than 9 and assessed all AIS codes associated with potential need for CD. The age group 16 years to 64 years was used as the comparator although overtriage in this group would skew the interpretation of our analyses in disfavor of older patients, which we were unable to adjust for. Finally, many of the differences yielded statistical significance, which not necessarily translates to clinical significance.

In summary, older trauma patients, irrespective of injury severity, were less often attended by doctor/paramedic teams, conveyed by air ambulance, or transported directly to a TC compared with younger adults. Time-critical interventions and primary survey x-ray imaging were less often performed on severely injured elderly trauma patients (NISS ≥ 25), although for patients with moderate to severe injuries (NISS < 25), prehospital time-critical interventions and clinical management in the ED showed no significant difference between age groups. When prehospital doctor/paramedic teams were attending the patients, no significant differences in prehospital advanced interventions were found between age groups. Overall, the Norwegian trauma system seems to be efficient, safe, and responsive for adult trauma patients met by a trauma team. However, our findings indicate that older adults are at risk of not receiving advanced prehospital care and that decisions made during dispatch have major consequences for the subsequent course. Improved dispatch of doctor/paramedic teams to older patients may make it more targeted and accessible to all age groups.

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AUTHORSHIP

M.C.-Ø. and E.J. participated in the acquisition and analysis of the data. M.C.-Ø., T.W., O.R., and E.J. contributed toward the interpretation of data for the article. M.C.-Ø. and E.J. drafted the article. E.J., T.W., and O.R. critically revised the article for intellectual content. All authors made substantial contributions to the conception and design of the work, provided final approval of the version to be published, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors attest to meeting the four ICMJE.org. authorship criteria.

DISCLOSURE

The authors declare no conflicts of interest.

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Appendix

Supplemental Digital Content

To *Differences in time-critical interventions and radiological examinations between adult and older trauma patients: A national register-based study*

- Supplementary Material 1: STROBE checklist.
- Supplementary Material 2: List of variables collected from the NTR and details about recategorization of selected variables.
- Supplementary Figure 1: Flowchart of patient inclusion from the NTR.
- Supplementary Table 1: Prehospital GCS, clinical management, and time-critical interventions stratified by NISS and age.
- Supplementary Table 2: Emergency Department physiologic parameters and clinical management stratified by age.
- Supplementary Table 3: Emergency Department radiological examinations stratified by age.
- Supplementary Table 4: Proportion of patients with severe injuries (AIS ≥3) who received an x-ray of the chest of pelvis on admission

Supplementary Material 1: STROBE checklist

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract *OK*
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found *OK*
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported *OK*
Objectives	3	State specific objectives, including any prespecified hypotheses *OK*
Methods		
Study design	4	Present key elements of study design early in the paper *OK*
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection *OK*
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *OK*
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed *Not applicable*
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable *OK. See list of variables extracted from NTR in the supplemental content.*
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group *OK*
Bias	9	Describe any efforts to address potential sources of bias *OK, see also limitations.*
Study size	10	Explain how the study size was arrived at *OK*
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why *OK*
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding *OK*
		(*b*) Describe any methods used to examine subgroups and interactions *OK*
		(*c*) Explain how missing data were addressed *OK*
		(*d*) If applicable, explain how loss to follow-up was addressed *Not applicable*
		(*e*) Describe any sensitivity analyses *OK*
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed *OK*

		(b) Give reasons for non-participation at each stage *Not applicable*
		(c) Consider use of a flow diagram *OK*
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders *OK*
		(b) Indicate number of participants with missing data for each variable of interest *OK*
		(c) Summarise follow-up time (eg, average and total amount) *Not applicable*
Outcome data	15*	Report numbers of outcome events or summary measures over time *OK*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included *OK*
		(*b*) Report category boundaries when continuous variables were categorized *OK*
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period *Not applicable*
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses *OK*
Discussion		
Key results	18	Summarise key results with reference to study objectives *OK*
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias *OK*
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence *OK*
Generalisability	21	Discuss the generalisability (external validity) of the study results *OK*
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based *OK*

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

Supplementary Material 2: List of variables collected from the NTR and details about recategorization of selected variables

The following variables were collected from the Norwegian Trauma Registry:

Data on age, gender, pre-injury physical status as defined by the American Society of Anesthesiologists physical status classification system (ASA-PS), place of injury, Abbreviated Injury Scale, New Injury Severity Scale, dominating injury type, mechanism of injury, prehospital Glasgow Coma Scale, prehospital advanced airway management and chest decompression, highest level of prehospital care provider, type of transportation, primary destination, emergency department status on intubation, chest drain insertion, x-ray of the chest and pelvis, computed tomography (CT) investigations, and time from hospital arrival to x-ray chest and to CT were collected from the NTR.

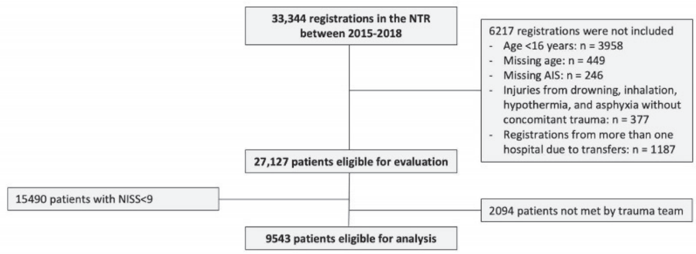
Three data items were re-categorized from its original NTR definitions:

1) For mechanism of injury, all motor vehicle, motorcycle, bicycle, and pedestrian injuries were merged to “Transport-related injuries” (TRI), except “Traffic: Other” which together with “Shot by firearm”, “Stabbed by sharp object”, “Stuck or hit by blunt object”, and “Explosions” were merged with “Other”.

2) Two categories of “Highest level of prehospital care provider”, “Level II: Basic Life Support” and “Level III: Advanced Life Support, no physician present”, were merged to “Ambulance personnel” together with “Other”.

3) Fixed- and rotor-wing (FW and RW) categories of “Type of transportation” were merged to “Air ambulance” (FW transport=0.6% of the study population). “Other” (Private/public vehicle, walk-in and police transport) was merged with “Ground ambulance”.

Supplementary Figure 1: Flowchart of patient inclusion from the NTR.



Supplementary Table 1: Prehospital Glasgow Coma Scale, clinical management and time-critical interventions stratified by NISS and age.

	NISS 9 through 14			NISS 15 through 24			NISS 25 through 75		
	16-64 years, n=3334 (49%)	≥65 years, n=1115 (41%)	P-value / Odds ratio with 95% CI	16-64 years, n=1904 (28%)	≥65 years, n=860 (32%)	P-value / Odds ratio with 95% CI	16-64 years, n=1594 (23%)	≥65 years, n=736 (27%)	P-value / Odds ratio with 95% CI
GCS[a], median (IQR)	15 (15-15)	15 (15-15)	0.139#	15 (14-15)	15 (14-15)	<0.001#	14 (6-15)	13 (6-15)	0.192#
GCS <9, n (%)	89 (3.1)	31 (3.3)		77 (5.0)	37 (5.3)		409 (31.2)	178 (30.9)	
GCS 9-13, n (%)	199 (7.0)	82 (8.7)	0.227	138 (8.9)	100 (14.3)	<0.001	211 (16.1)	123 (21.4)	0.018
GCS 14-15, n (%)	2548 (89.8)	831 (88.0)		1329 (86.1)	561 (80.4)		689 (52.6)	275 (47.7)	
Highest level of prehospital care provider[b], n (%)									
Physician	702 (22.5)	175 (16.9)	0.70 (0.58 - 0.84)	584 (33.2)	188 (23.4)	0.61 (0.51 - 0.74)	746 (50.1)	217 (32.0)	0.47 (0.39 - 0.57)
Ambulance personell or other**	2423 (77.5)	862 (83.1)		1174 (66.8)	617 (76.6)		744 (49.9)	461 (68.0)	
Physician attendance if GCS<9	29 (32.6)	8 (25.8)	0.72 (0.29 - 1.80)	29 (37.7)	15 (41.7)	1.18 (0.53 - 2.65)	274 (68.0)	87 (49.2)	0.46 (0.32 - 0.65)
Advanced airway management[c], n (%)	49 (1.5)	19 (1.8)	1.16 (0.68 - 1.98)	59 (3.2)	22 (2.6)	0.81 (0.49 - 1.33)	336 (22.0)	102 (14.4)	0.60 (0.47 - 0.76)
If GCS<9	24 (27.0)	8 (25.8)	0.94 (0.37 - 2.39)	29 (37.7)	15 (40.5)	1.13 (0.51 - 2.52)	252 (62.2)	78 (44.1)	0.48 (0.33 - 0.68)
Chest decompression[d], n (%)	NA*	NA*	0.264&	8 (0.4)	5 (0.6)	0.561&	59 (3.9)	13 (1.8)	0.46 (0.25 - 0.85)
Type of transportation[e], n (%)									
Air ambulance	535 (16.7)	133 (12.4)	0.71 (0.58 - 0.87)	486 (27.0)	147 (18.0)	0.60 (0.48 - 0.73)	537 (35.6)	156 (22.8)	0.53 (0.43 - 0.66)
Ground ambulance or other ***	2672 (83.3)	939 (87.6)		1313 (73.0)	668 (82.0)		972 (64.4)	529 (77.2)	
Air ambulance transportation, n (%)									
If GCS<9	16 (18.0)	4 (12.9)	0.68 (0.21 - 2.20)	18 (23.4)	8 (22.2)	0.94 (0.36 - 2.41)	177 (43.7)	54 (30.3)	0.56 (0.39 - 0.82)
Primary destination[f]:									
Trauma center, n (%)	1161 (34.8)	340 (30.5)		840 (44.1)	362 (42.1)		979 (61.4)	381 (51.8)	
Acute care trauma hospital, n (%)	2173 (65.2)	775 (69.5)	0.82 (0.71 - 0.95)	1064 (55.9)	498 (57.9)	0.92 (0.78 - 1.08)	615 (38.6)	355 (48.2)	0.67 (0.57 - 0.80)
Prehospital time[g], minutes, median (IQR)	61 (38-96)	68 (44-104)	<0.001#	68 (40-101)	70 (44-109)	0.005#	65 (37-102)	67 (43-99)	0.104#
Minutes, mean (SD)	76 (65)	84 (67)	0.001§	81 (66)	95 (105)	0.001$	83 (90)	90 (98)	0.125§

Abbreviations: GCS, Glasgow Coma Scale; IQR, inter quartile range; NA, not applicable; NISS, New Injury Severity Scale;

#Mann-Whitney *U*; §Independent sample t-test; $Unequal variances t-test

*NA: Not reported due to low patient numbers. ** "Other" includes 65 (G1) and 12 (G2) patients. *** "Other" includes 197 (G1) and 59 (G2) patients.

Missing data by increasing NISS interval for G1 and G2, respectively: a: 15%, 19%, 18% and 15%, 19%, 19%; b: 6%, 8%, 7% and 7%, 6%, 8%; c: 4%, 4%, 4% and 4%, 3%, 4%; d: 4%, 4%, 4% and 4%, 3%, 3%; e: 4%, 6%, 5% and 4%, 5%, 7%. f: 0%; g: 14%, 16%, 16% and 14%, 16%, 20%.

Supplementary Table 2: Emergency department (ED) physiologic parameters and clinical management stratified by age

	Group 1: 16-64 years, n=6832 (72%)	Group 2: ≥65 years, n=2711 (28%)	P-value / Odds ratio with 95% CI	65 – 74 years, n=1353 (50%)	75 – 84 years, n=836 (31%)	≥ 85 years, n=522 (19%)
GCS[a], median (IQR)	15 (14-15)	15 (14-15)	<0.001#	15 (14-15)	15 (14-15)	15 (13-15)
GCS <9, n (%)	407 (6.5)	197 (8.0)	<0.001	80 (6.5)	58 (7.6)	59 (12.7)
GCS 9-13, n (%)	506 (8.1)	283 (11.5)		118 (9.6)	94 (12.3)	71 (15.3)
GCS 14-15, n (%)	5336 (85.4)	1982 (80.5)		1033 (83.9)	614 (80.2)	335 (72.0)
SBP[b] (mm Hg), mean (SD)	133 (23.5)	144 (30.8)	<0.001§	141 (29.0)	145 (30.2)	150 (35.0)
<90 mm Hg, n (%)	236 (3.5)	128 (4.8)	0.004	69 (5.2)	28 (3.4)	31 (6.0)
Endotracheal intubation[c], n (%)	603 (8.8)	218 (8.0)	0.90 (0.77 - 1.06)	109 (8.1)	71 (8.5)	38 (7.3)
If ED GCS<9, n (%)	204 (50.1)	93 (47.2)	0.89 (0.63 - 1.25)	46 (57.5)	28 (48.3)	19 (32.2)
ED chest drain[d], n (%)	559 (8.6)	198 (7.7)	0.88 (0.75 - 1.05)	102 (7.9)	60 (7.6)	36 (7.2)

Abbreviations: ED, emergency department; GCS, Glasgow Coma Scale; IQR, inter quartile range; SBP, systolic blood pressure

#Mann-Whitney *U*; §Unequal variances t-test.

Missing data for G1 and G2, respectively: a: 9% and 9%; b: 2% and 2%; c: 0%; d: 5% and 5%.

Supplementary Table 3: Emergency department (ED) radiological examinations stratified by age

	Group 1: 16-64 years, n=6832 (72%)	Group 2: ≥65 years, n=2711 (28%)	P-value / Odds ratio with 95% CI	65 – 74 years, n=1353 (50%)	75 – 84 years, n=836 (31%)	≥ 85 years, n=522 (19%)
X-ray chest[a], n (%)	6293 (92.2)	2470 (91.1)	0.87 (0.75 - 1.02)	1243 (91.9)	760 (91.0)	467 (89.5)
X-ray pelvis[b], n (%)	5265 (77.2)	2028 (75.0)	0.89 (0.80 - 0.98)	1017 (75.3)	625 (75.2)	386 (74.1)
CT[c], n (%)	6073 (88.9)	2442 (90.1)	1.14 (0.98 - 1.32)	1225 (90.7)	755 (90.4)	461 (88.3)
Time to X-ray chest[d] (min.), median (IQR)	5 (3-8)	5 (3-9)	NP	5 (3-8)	5 (3-9)	5 (4-9)
Mean (SD)	7.4 (8.7)	8.1 (10.4)	0.002§	7.7 (8.8)	7.9 (9.6)	9.7 (14.8)
Within 15 min (%)	92,8	91,3	NP	91,7	91,1	90,4
Within 60 min (%)	99,3	98,7	NP	99,2	99,2	96,5
Time to CT[e] (min.), median (IQR)	29 (22-40)	30 (22-39)	NP	30 (22-38)	30 (22-40)	30 (25-40)
Mean (SD)	32.3 (14.6)	33.0 (14.9)	0.086§	32.3 (14.6)	33.4 (15.5)	34.0 (14.6)

Abbreviations: CT, computed tomography; IQR, inter quartile range; min, minutes; NISS, New Injury Severity Score; NP, not performed; SD, standard deviation.

§Independent samples T-test

Missing data for G1 and G2, respectively: a, b, and c: 0%. d: 15% and 16%. e: 20% and 21%.

Supplementary Table 4: Proportion of patients with severe injuries (AIS >3) who received an x-ray of the chest or pelvis on admission.

	AIS thorax ≥3			AIS abdomen ≥3			AIS pelv. and lower extr. ≥3		
	16-64 years, n=2052	≥65 years, n=896	P-value	16-64 years, n=629	≥65 years, n=109	P-value	16-64 years, n=981	≥65 years, n=360	P-value
X-ray chest									
Yes	1955 (95.3)	827 (92.3)	0.001	580 (92.4)	106 (97.2)	0.066*			
No	96 (4.7)	69 (7.7)		48 (7.6)	3 (2.8)				
X-ray pelvis									
Yes				452 (72.2)	77 (70.6)	0.738	872 (89.1)	305 (84.7)	0.031
No				174 (27.8)	32 (29.4)		107 (10.9)	55 (15.3)	

Abbreviations: AIS, Abbreviated Injury Scale.

*Fisher's exact test

10.3 Paper III

Cuevas-Østrem *et al.*
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Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine

ORIGINAL RESEARCH **Open Access**

Care pathways and factors associated with interhospital transfer to neurotrauma centers for patients with isolated moderate-to-severe traumatic brain injury: a population-based study from the Norwegian trauma registry

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Abstract

Background Systems ensuring continuity of care through the treatment chain improve outcomes for traumatic brain injury (TBI) patients. Non-neurosurgical acute care trauma hospitals are central in providing care continuity in current trauma systems, however, their role in TBI management is understudied. This study aimed to investigate characteristics and care pathways and identify factors associated with interhospital transfer to neurotrauma centers for patients with isolated moderate-to-severe TBI primarily admitted to acute care trauma hospitals.

Methods A population-based cohort study from the national Norwegian Trauma Registry (2015–2020) of adult patients (≥ 16 years) with isolated moderate-to-severe TBI (Abbreviated Injury Scale [AIS] Head ≥ 3, AIS Body < 3 and maximum 1 AIS Body = 2). Patient characteristics and care pathways were compared across transfer status strata. A generalized additive model was developed using purposeful selection to identify factors associated with transfer and how they affected transfer probability.

Results The study included 1735 patients admitted to acute care trauma hospitals, of whom 692 (40%) were transferred to neurotrauma centers. Transferred patients were younger (median 60 vs. 72 years, $P < 0.001$), more severely injured (median New Injury Severity Score [NISS]: 29 vs. 17, $P < 0.001$), and had lower admission Glasgow Coma Scale (GCS) scores (≤ 13: 55% vs. 27, $P < 0.001$). Increased transfer probability was significantly associated with reduced GCS scores, comorbidity in patients < 77 years, and increasing NISSs until the effect was inverted at higher

Meetings: Extracts of this study were presented at the London Trauma Conference, December 8th, 2022.

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scores. Decreased transfer probability was significantly associated with increasing age and comorbidity, and distance between the acute care trauma hospital and the nearest neurotrauma center, except for extreme NISSs.

Conclusions Acute care trauma hospitals managed a substantial burden of isolated moderate-to-severe TBI patients primarily and definitively, highlighting the importance of high-quality neurotrauma care in non-neurosurgical hospitals. The transfer probability declined with increasing age and comorbidity, suggesting that older patients were carefully selected for transfer to specialized care.

Keywords Traumatic Brain Injury, Trauma system, Transfer, Interhospital, Geriatric

Introduction

Traumatic brain injury (TBI) is one of the leading causes of death and disability after trauma, resulting in approximately 2 million hospital admissions in Europe annually [1, 2]. The highest admission rates are seen in older patients, and as many countries face aging populations, this burden will likely increase [1, 2]. Systems ensuring continuity of care through the treatment chain improve outcomes for TBI patients [1, 3]. In current trauma systems, non-neurosurgical acute care trauma hospitals (ACTHs) are central in providing care continuity, but few studies have addressed their role in TBI management.

TBI patients primarily admitted to ACTHs may receive definitive care there or undergo interhospital transfer to a neurotrauma center (NTC) for access to neurosurgery or neurocritical care [4–7]. Patients who do not require neurosurgery or neurocritical care are recommended to receive definitive care at ACTHs. Furthermore, patients deemed ineligible for transfer due to unsalvageable injuries or have risk factors for a dismal prognosis despite interventions, such as very advanced age, significant comorbidity, or severe frailty, are also candidates for receiving definitive care at ACTHs [4, 8–15].

Previous studies have largely focused on patients admitted to NTCs [16, 17], so what characterizes patients presenting to ACTHs and their care pathways in a national system is poorly described. Moreover, the impact of advanced age and comorbidity on transfer decisions and treatment intensity is debated [18]. Studies of patients admitted to ACTHs have been limited to analyses of administrative databases [19], small sample sizes [14], narrow inclusion criteria [8], or data from a subset of hospitals in a national system [20]. More knowledge about the case-mix non-neurosurgical hospitals face and which patients they transfer to NTCs is important for further trauma system development [10].

We provide a population-based study from all ACTHs in a nationwide integrated trauma system. This provides a unique opportunity to investigate care for TBI patients outside NTCs from a setting that shares characteristics with trauma systems internationally, such as field triage tools and centralized neurosurgical services [7]. The Norwegian Trauma Registry's (NTR) status as a national clinical quality registry warrants a law-regulated mandatory data delivery from all trauma-receiving hospitals by certified registrars. Understanding these patients' care pathways and factors associated with transfer are important to evaluate how patients are identified for transfer, particularly regarding the older population. Consequently, this can inform targeted training, education, and system development to improve patient outcomes. The aim of this study was to describe characteristics and care pathways and identify factors associated with interhospital transfer to NTCs for patients with isolated moderate-to-severe TBI primarily admitted to non-neurosurgical ACTHs.

Methods

Study design and ethics

We extracted deidentified data from the NTR to conduct a national register-based study of adult cases with isolated moderate-to-severe TBI in Norway between January 1, 2015, and December 31, 2020, in line with the study protocol and the STROBE guidelines [21, 22]. Patients were compared across interhospital transfer status. Patients directly admitted to NTCs were included only for an overview of all care pathways and to calculate definitive care proportions. The NTR operates with a waiver of consent and all registered patients receive opt-out information. This study was approved by the Oslo University Hospital data protection officer (No. 19/16593). According to Norwegian legislation, approval from an ethics committee is not required for studies of deidentified registry data for health service research.

Setting

Norway's publicly funded healthcare system serves a population of 5.4 million people. A nationwide trauma system with uniform requirements for all prehospital services and all 38 hospitals has been implemented, including field triage criteria (Supplementary Fig. 1) [7, 23]. Patients with moderate-to-severe TBI receive 24/7 neurosurgical and neurocritical care services at all four regional referral trauma centers (TCs) and one ACTH (Stavanger University Hospital), jointly called NTCs in this study (Level I/II TCs [24]) (Supplementary Fig. 2). All 38 hospitals have 24/7 trauma team availability, emergency general surgery, and critical care and high-dependency units (i.e., CCUs/HDUs, intensive care, and postoperative care units).

Data collection

The NTR is a mandatory clinical quality registry that has collected national data since 2015. Patients admitted to TCs and ACTHs who are (1) admitted through trauma team activation (TTA) or (2) admitted without TTA but found to have (a) penetrating injuries to the head, neck, torso, or extremities proximal to the knee or elbow, (b) head injury with Abbreviated Injury Scale (AIS) score ≥ 3, or (c) New Injury Severity Score (NISS) > 12, or (3) die at the scene of injury or during transportation to the hospital where prehospital management has been initiated are registered [25–27]. Registrars search electronic hospital databases and emergency admission protocols for patients not admitted through TTA who meet inclusion criteria. The estimated patient coverage is >90% [26]. Data collection is based on the Utstein template, and injuries are coded according to the AIS manual 2005 (update 2008) by Association for the Advancement of Automotive Medicine certified nurse registrars [28, 29].

Selection of participants

Patients primarily admitted to ACTHs aged 16 years or older with isolated moderate-to-severe TBI were included (Fig. 1). Isolated moderate-to-severe TBI, i.e., absence of significant extracranial injuries, was defined as (1) head injury with AIS scores of 3 to 6; (2) no extracranial AIS scores higher than 2; and (3) a maximum of one extracranial injury with an AIS score of 2. This definition was chosen to identify a population in which TBI would be the reason for considering a transfer to NTCs. It aligns with previous studies of isolated moderate-to-severe TBI and the Norwegian trauma guideline that recommends transfer of patients with injuries in three or more body regions, while allowing patients with extracranial injuries unlikely to affect transfer decision or outcome considerably to be included [7, 30, 31]. An AIS Head score of ≥3 reflects detectable intracranial pathology or cranial fractures on CT. Patients with chronic subdural hematoma without concomitant trauma were excluded. The study population was stratified by care pathways.

Study variables

Patient characteristics were compared between transferred and nontransferred patients regarding

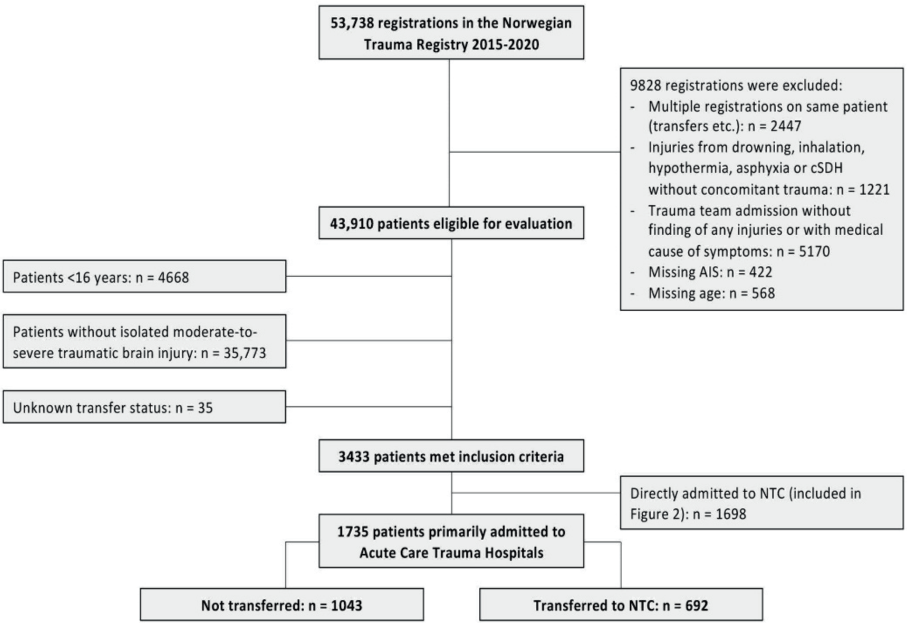

Fig. 1 Flowchart of the study population. Abbreviations: AIS, Abbreviated Injury Scale; cSDH, Chronic subdural hematoma; NTC, Neurotrauma center

demographics, injury characteristics, management, and mortality. Care pathways were reported as primary admission rates to ACTHs and NTCs, transfer rates from ACTHs to NTCs, and definitive care rates at ACTHs and NTCs. Patients primarily admitted to NTCs were included only in care pathway analyses (Fig. 1).

Variables extracted from the NTR are listed in Supplementary Table 1 with details regarding operationalizing. Information about head injury types was derived from AIS Head codes according to Supplementary Table 2. Patients with multiple different head injuries were registered in more than one category. NISS is calculated from the sum of the square of the three highest AIS codes irrespective of body regions, which, due to the study's inclusion criteria, largely reflects the overall severity of head injuries [27]. The Glasgow Coma Scale (GCS) score was registered as the first GCS score upon admission unless the patient had undergone prehospital intubation, whereas the last GCS score before sedation was registered. GCS scores were categorized according to the Head Injury Severity Scale (HISS) [32]. Road distances from ACTHs to their corresponding NTCs according to the trauma plan were calculated using OpenStreetMap (www.openstreetmap.org/copyright – OpenStreetMap Foundation, Cambridge, United Kingdom) (Supplementary Table 3). The injury site's municipality number was mapped to the 2017 urban-rural classification system Centrality Index of Norway and categorized as "major urban Norway", "minor urban Norway" and "rural Norway" (categories 1 and 2, 3 and 4, and 5 and 6, respectively) [33].

Statistical analyses

Continuous data with a nonnormal distribution are presented as medians with interquartile ranges (IQRs), and categorical data are reported as numbers and percentages. Baseline characteristics were compared using the Mann–Whitney U test for continuous data and the χ^2 test for categorical variables. A P value < 0.05 (two-tailed) was considered statistically significant.

To identify factors significantly associated with interhospital transfer from ACTHs to NTCs, a generalized additive model (GAM) was developed according to the purposeful selection modeling strategy [34]. This procedure tests all relevant variables in univariable analysis for statistical significance before entering them into a multivariable model. Furthermore, the procedure tests for interaction and nonlinear terms and adds them if needed. Interactions reflect that the effects of each variable in the interaction term are not constant across all levels of the other variable. Age (continuous), sex, preinjury American Society of Anesthesiologists physical status (ASA-PS) [35], year of incident, injury site's urban-rural classification [33], distance from ACTH to NTC (km, continuous), injury mechanism, GCS score on admission to ACTHs (HISS), and NISS (continuous) were considered important before analysis [11, 36, 37]. Because of missing data in some of the covariates (Table 1), multiple imputation was performed based on a missing at random assumption [38, 39]. For missing GCS scores on admission to ACTHs, next observation carried backward imputation was used instead of multiple imputation when GCS scores from an NTC were available. Following the purposeful selection procedure, the following interactions were deemed clinically relevant and evaluated in the model development: age*ASA-PS; age*NISS; age*ASA-PS*NISS; age*ACTH-NTC distance; NISS*ACTH-NTC distance; and age*GCS score. Assumptions about linearity were checked, and variables age and NISS were determined to be nonlinear. Estimates for the regression coefficients are presented as odds ratios (ORs) with 95% confidence intervals (CIs), and the effective degrees of freedom (edf) are given for nonlinear terms and visualized as contour plots. Statistical analyses were performed using SPSS v.27 (IBM Corp., Armonk, NY) and R statistical software (v.4.2.0; R Core Team, 2022) using the mgcv-package [40].

Results

Study population characteristics, mortality, and care pathways

The study cohort included 1735 patients with a median age of 67 years (IQR 49–80); 68% were male, the median preinjury ASA-PS score was 2 (IQR 1–3), 35% had an admission GCS score ≤ 13, the median NISS was 22 (IQR 14–30), and 50% had an AIS Head score ≥ 4 (Fig. 1; Table 1). The unadjusted 30-day mortality was lowest in the transferred group (13.1% vs. 17.4%, P = 0.019) (Table 1).

Forty percent (n = 692) of patients primarily admitted to ACTHs were transferred to NTCs (Figs. 1 and 2). Definitive care rates at NTCs were 76–80% for patients up to 65 years of age (Fig. 2). For those older than 65 years of age, this decreased with increasing age, resulting in 32–47% of patients receiving definitive care at ACTHs as a result of higher primary admission rates to ACTHs and decreasing interhospital transfer rates.

Factors associated with interhospital transfer

Transferred patients were compared to nontransferred patients in univariate analysis (Table 1) and were younger (median 60 vs. 72 years, P < 0.001; proportion ≥ 65 years: 40% vs. 63%, P < 0.001), more often male (75% vs. 63%, P < 0.001), and had less comorbidity (preinjury ASA-PS ≥ 3: 26% vs. 29%, P = 0.015). Transferred patients were also more severely injured (median NISS: 29 vs. 17, P < 0.001; maximum AIS Head score ≥ 4: 66% vs. 40%, P < 0.001), had lower GCS scores at admission to ACTHs (GCS ≤ 13: 55% vs. 27%, P < 0.001), had higher

Table 1 Demographics, injury characteristics and outcome for adult patients with isolated moderate-to-severe traumatic brain injury primarily admitted to acute care trauma hospitals, by transfer status to a neurotrauma center

	All patients (n = 1735)	Not transferred (n = 1043)	Transferred (n = 692)	*P* value[a]	Missing
Patient age, median (IQR)	67 (49–80)	72 (53–84)	60 (42–71)	< 0.001	0.0%
Sex				< 0.001	0.0%
Female	563 (32.4)	387 (37.1)	176 (25.4)		
Male	1172 (67.6)	656 (62.9)	516 (74.6)		
Preinjury ASA-PS				0.015	3.7%
Normal health	572 (34.3)	334 (32.9)	238 (36.4)		
Mild systemic disease	641 (38.4)	392 (38.6)	249 (38.1)		
Severe systemic disease	423 (25.3)	276 (27.2)	147 (22.5)		
Severe systemic disease that is a constant threat to life	34 (2.0)	14 (1.4)	20 (3.1)		
Mechanism of injury				0.009	5.0%
Traffic-related	244 (14.8)	154 (15.3)	90 (14.0)		
Low energy fall[b]	834 (50.6)	536 (53.2)	298 (46.4)		
High-energy fall	404 (24.5)	227 (22.5)	177 (27.6)		
Other	167 (10.1)	90 (8.9)	77 (12.0)		
Injury site's centrality class[c]				0.693	6.3%
Major urban Norway	483 (29.7)	291 (29.0)	192 (30.9)		
Minor urban Norway	938 (57.7)	587 (58.5)	351 (56.5)		
Rural Norway	204 (12.6)	126 (12.5)	78 (12.6)		
Distance between ACTH and NTC[d]				0.376	0.0%
Kilometers, median (IQR)	103 (55–220)	103 (55–220)	123 (61–195)		
NISS, median (IQR)	22 (14–30)	17 (14–25)	29 (22–41)	< 0.001	0.0%
Maximum AIS Head score				< 0.001	0.0%
3	862 (49.7)	628 (60.2)	234 (33.8)		
4	402 (23.2)	249 (23.9)	153 (22.1)		
5-6[e]	471 (27.2)	166 (15.9)	305 (44.1)		
GCS score on admission				< 0.001	17.5%
14–15	933 (65.2)	746 (73.4)	187 (45.2)		
9–13	269 (18.8)	144 (14.2)	125 (30.2)		
<9	229 (15.6)	127 (12.5)	102 (24.6)		
Type of head injury[f]					0.0%
Subdural hematoma	1120 (64.6)	635 (60.9)	485 (70.1)	< 0.001	
Skull fracture	818 (47.1)	391 (37.5)	427 (61.7)	< 0.001	
tSAH	742 (42.8)	367 (35.2)	375 (54.2)	< 0.001	
Contusion	731 (42.1)	349 (33.5)	382 (55.2)	< 0.001	
Epidural hematoma	191 (11.0)	53 (5.1)	138 (19.9)	< 0.001	
Brain stem	62 (3.6)	17 (1.6)	45 (6.5)	< 0.001	

Table 1 (continued)

	All patients (n = 1735)	Not transferred (n = 1043)	Transferred (n = 692)	*P* value[a]	Missing
Highest level of in-hospital care[g]				< 0.001	1.1%
General ward	373 (21.7)	342 (33.3)	31 (4.5)		
CCU/HDU	1295 (75.5)	662 (64.5)	633 (91.7)		
Other	48 (2.8)	22 (2.1)	26 (3.8)		
30-day mortality	265 (15.7)	176 (17.4)	89 (13.1)	0.019	2.5%

Abbreviations: ACTH, Acute care trauma hospital; AIS, Abbreviated Injury Scale; ASA-PS, American Society of Anesthesiologists physical status; CCU/HDU, Critical care or high-dependency unit; GCS, Glasgow Coma Scale; IQR, Interquartile range; NISS, New Injury Severity Score; NTC, Neurotrauma Center; tSAH, Traumatic subarachnoid hemorrhage

Data reported as n (%) unless stated otherwise

[a] *P* values were derived from the Mann-Whitney *U* test for continuous data and chi-squared test for categorical data, testing the null hypothesis of no difference between strata

[b] Low-energy fall is defined as a fall from standing or up to one meter

[c] Centrality class according to Statistics Norway 2017 Centrality Index

[d] Driving distance between the ACTH where the patient was primarily referred and the corresponding NTC according to the national trauma plan

[e] A total of five patients had AIS Head scores of 6 and none were transferred

[f] Type of head injury was derived from AIS codes. More than one type of head injury may be described per patient, including injuries with AIS Head scores < 3 for those who had at least one AIS Head score ≥ 3

[g] Highest level of in-hospital care reported at the definitive care hospital level. Other includes emergency department, operating room, and other

frequencies of all head injury types (all P < 0.001), and had higher admission rates to CCUs/HDUs (92% vs. 65%, P < 0.001). The subgroups were injured in equally urban-rural parts of Norway and with similar distances between ACTHs and corresponding NTCs. Transferred patients were more severely injured across all age groups (Suppl. Figure 3).

The final GAM (Table 2) identified factors significantly associated with interhospital transfer to NTCs and how they affected transfer probability. An increased transfer probability was associated with reduced GCS scores (GCS 9–13: OR 2.78 [95% CI 2.03–3.81], P < 0.001; GCS 3–8: 1.70 [95% CI 1.23–2.34], P = 0.001) and typically with increasing NISS. NISS interacted with age, and NISS' effect on transfer probability showed an inverted U-shape for patients aged < 80 years, where the probability increased for NISSs up to 50–60 and decreased for higher NISSs (Fig. 3A). For patients with NISS > 20, a rapid decrease in transfer probability was observed from 70 to 80 years. For patients > 80 years, NISS had almost no impact on the transfer probability. A decreased transfer probability was associated with increasing age (Table 2), except for patients with preinjury ASA-PS 1–2 and extreme NISSs (< 15 or > 70) (Fig. 3A). Preinjury ASA-PS 3–4 was associated with an increased transfer probability for younger patients, but this effect rapidly decreased with age and was associated with a lower transfer probability compared to ASA-PS 1–2 patients from age 77 years (Suppl. Figures 4 and 5).

NISS also interacted with the distance between the ACTH and the nearest NTC (Fig. 3B); for patients with NISSs greater than 30, the probability decreased with increasing distance; for NISSs between 20 and 30, the probability was roughly constant with increasing distance; and for patients with NISSs of 9–20, the probability increased slightly with increasing distance. A decreased transfer probability was also associated with the incident year (OR 0.87 [95% CI 0.82–0.94], p < 0.001), describing a decreased transfer probability throughout the study period.

Discussion

In this population-based study from a national integrated trauma system, 40% of patients primarily admitted to ACTHs with isolated moderate-to-severe TBI were transferred to NTCs. Transferred patients were younger and more severely injured than nontransferred patients. An increased transfer probability was associated with factors reflecting the number and severity of head injuries; a reduced GCS score and an increased NISS, as well as comorbidities in patients aged < 77 years. However, for very high NISSs, the transfer probability declined. A decreased transfer probability was associated with increasing age and comorbidity in older patients, and distance between the ACTH and the nearest NTC, except in patients with extreme NISSs. These novel findings demonstrated that a substantial number of patients with isolated moderate-to-severe TBI were managed both primarily and definitively by ACTHs and that careful secondary triage was performed at admission to identify patients anticipated to benefit from specialized care.

The association between injury severity and transfer was as expected, as current guidelines emphasize GCS scores and radiological imaging results when evaluating

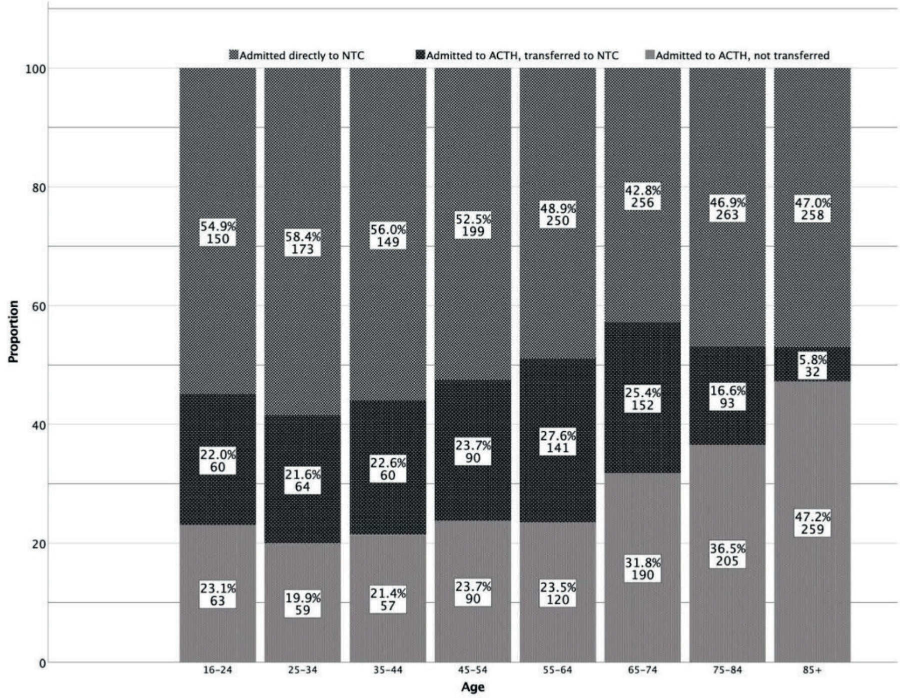

Fig. 2 Care pathways for patients with isolated moderate-to-severe TBI
Admission rates to ACTHs and NTCs as primary hospitals and interhospital transfer rates to NTCs, by age. Definitive care at an NTC is composed of patients directly admitted to an NTC and interhospital transfers. Primary admission to an ACTH is composed of patients not transferred and transferred from an ACTH.
Abbreviations: ACTH, Acute care trauma hospital; NTC, Neurotrauma center

TBI patients for transfer to specialized care [4, 7]. According to the study inclusion criteria, NISS largely reflected the number and severity of head injuries, and although NISS is a retrospectively calculated score, it is predominantly based on CT imaging, which is performed shortly after admission [41]. Interestingly, the transfer probability decreased for patients with NISSs > 50–60 and age < 80, reflecting a tipping point where injuries are so severe that transfer to advanced care in NTCs has likely been considered non-beneficial for some patients.

The Brain Trauma Foundation guidelines do not state an upper age limit for neurosurgical care [4]; however, studies have found advanced age to be associated with lower treatment intensity, and the incidence of emergency neurosurgery has been found to peak at age 75 [18, 42, 43]. Our study identified a rapid decrease in transfer probability at the same ages. Advanced age and comorbidities are known risk factors for poor prognoses [11, 44], and their association with reduced transfer probabilities is thus likely an expression of anticipated non-beneficence (Table 2; Fig. 3, Supplementary Fig. 4). Preinjury ASA-PS score 3–4 was, however, associated with an increased transfer probability for patients < 77 years, while it contributed to a decreased transfer probability for older patients (Supplementary Figs. 4 and 5). Comorbidities increase the risk of complicated clinical trajectories, which may be better managed at more resourceful hospitals. Thus, we believe this reflects a lower threshold for transfer in case of complications in patients expected to be able to benefit from specialized care.

Primary admission rates to ACTHs were highest for patients ≥ 65 years old (Fig. 2), which must be seen in light of prehospital triage tools' limitations in detecting

Table 2 Factors associated with interhospital transfer from acute care trauma hospitals to neurotrauma centers for patients with moderate-to-severe traumatic brain injury

	OR (95% CI)	edf	*P* value
GCS score			
14–15	1.00	N/A	
9–13	2.78 (2.03–3.81)	N/A	<0.001
3–8	1.70 (1.23–2.34)	N/A	0.001
Preinjury ASA-PS			
1–2	1.00	N/A	
3–4	9.11 (1.66–49.94)	N/A	0.011
ASA 1–2*age	0.94 (0.90–0.997)	N/A	0.038
ASA 3–4*age	0.92 (0.87–0.97)	N/A	0.003
Year of incident	0.88 (0.82–0.94)	N/A	<0.001
s(age)	N/A	2.92	<0.001
s(NISS)	N/A	3.65	<0.001
ti(age, NISS)	N/A	1.73	<0.001
ti(NISS, distance)	N/A	0.88	0.008

Abbreviations: ASA-PS, American Society of Anesthesiologists physical status; edf, Effective degrees of freedom; GCS, Glasgow Coma Scale; N/A, Not applicable; NISS, New Injury Severity Score; s, smoothed term; ti, smoothed interaction term

moderate-to-severe TBI for direct NTC transport in older patients [45]. Low-energy injury mechanisms are increasingly frequent with advanced age but are not well captured by the current triage guidelines (Supplementary Fig. 1), and caused 51% of injuries in the study population (Table 1). Studies have found that GCS scores are often higher for older adults than younger adults with similar anatomical injury severity [46]. The high proportion of patients with GCS scores of 14–15 at presentation to ACTHs in this study (64%, Table 1) indicates that this is an explanation for the observed increase in ACTH primary admission rates with age.

The interaction between NISS and the distance between ACTHs and NTCs was significantly associated with transfer (Fig. 3B). The increased transfer probability for patients with NISSs of 9–20 admitted to ACTHs far from the nearest NTC likely reflects proactivity regarding uncertain clinical development. The decreasing transfer probability with increasing distance for patients with NISSs > 30 likely reflects 'the window of opportunity' for performing successful neurosurgical interventions. Long transfer distances may cause a time to neurosurgery that exceeds this window even with the use of air ambulance transport. Interestingly, the distance between the ACTH and the nearest NTC was not significantly associated with transfer independently. Nor was the injury site's centrality class, sex, or mechanism of injury, reflecting that these factors did not significantly affect transfer decisions.

Nontransferred patients had a higher 30-day mortality rate than transferred patients (Table 1), in line with previous studies [14]. This unadjusted mortality rate reflects the effect of NTC care, but also case-mix differences and the fact that the nontransferred subgroup encompassed patients treated with low intensity both due to nonsevere injuries and due to very severe injuries deemed unsalvageable or ineligible for specialized care (Table 1, Supplementary Fig. 3), as seen in other studies [13, 14, 18].

The incident year was negatively associated with transfer which suggests a decreased transfer probability throughout the study period. However, in the same period, the NTR matured, and increasing numbers of hospitals systematically searched for patients who met the registry inclusion criteria who had been admitted without TTA [26]. An increase in registrations of such patients from ACTHs over time would give the observed effect and is the most likely explanation for this finding. Therefore, it was necessary to adjust for this in the model. No changes in the trauma system have occurred that would cause a real decrease in transfer probability.

Limitations

This study has limitations. First, the design is retrospective and observational, and we could only establish associations between various factors and probability for transfer, not cause-and-effect relationships. Second, information about factors that could have influenced transfer decisions beyond the confounders we adjusted for, including the use of antithrombotic medications, frailty, preinjury institutional living, pupil reactivity, GCS score deterioration (trends), neurological symptoms (e.g., lateralizing signs) or patient's or relatives' wishes, was not available from the NTR [7, 11, 12, 37, 44, 47]. This may have led to imprecise estimates, although most likely of minor impact because the included variables are those emphasized by current guidelines [4, 7]. Additionally, some of these factors with unavailable information are included in the national criteria for interhospital transfer as outlined in the national trauma plan (Supplementary Table 4), which we therefore could not use to evaluate transfer adequacy. Third, there is a risk that selection biases may have occurred from failure to identify patients at ACTHs for the NTR. The Scandinavian TBI guidelines' recommendation of hospital admission for TBI patients with CT findings and the NTR's registrar's efforts to identify patients with AIS Head ≥3 likely counteracted this [26, 48]. In addition, the publicly funded health services likely reduced socioeconomically driven biases. Fourth, we used an AIS definition of moderate-to-severe TBI, which led to the inclusion of patients with mild TBI according to the HISS GCS classification (Table 1). Using a multidimensional measure of TBI severity has been advocated, e.g., combining AIS and GCS definitions. We chose to only use the AIS definition to include a population with a high degree of CT-diagnosed head injury reflecting real-world equipoise and practice for clinicians in ACTHs and to better capture older patients [46]. Fifth, the GAM contained six

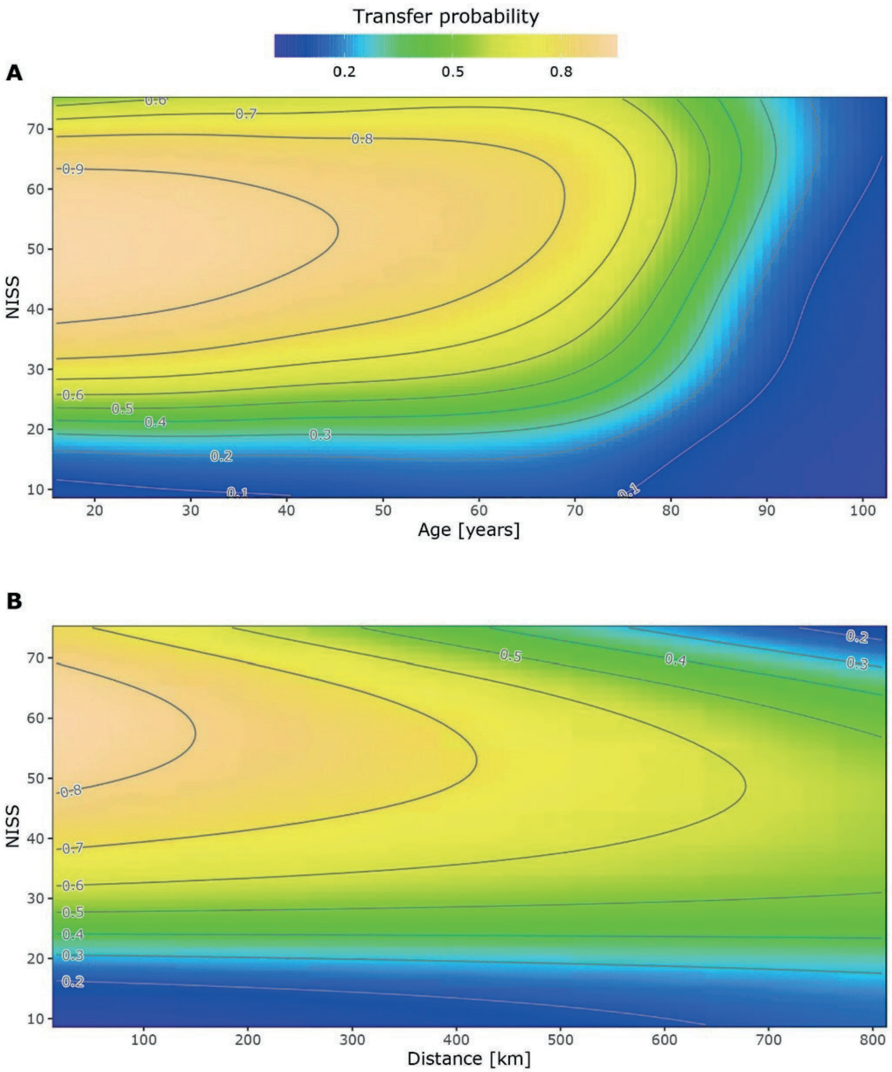

Fig. 3 Contour plots showing the estimated probability for interhospital transfer as (**A**) NISS and patient age changes and (**B**) NISS and road distance between ACTHs and NTCs in kilometer changes, as a function of the full model. Other covariates are fixed at their median and mode values for continuous and categorical data, respectively. The distance between contour lines represents a 10% change in transfer probability

independent variables that cover a wide spectrum of potential patient cases. The dataset used to fit the model had poor coverage for atypical patients, e.g., patients with high pre-injury ASA-PS (3–4) and ages below 50 years or patients with NISSs>50. Thus, care should be taken to make inferences about atypical patients. Sixth, highly relevant information about neurosurgical interventions among patients who underwent transfer was unfortunately not available from the NTR but has been studied elsewhere [43]. Neurosurgical procedures are not performed outside NTCs in Norway. Finally, although the setting and demographics share important characteristics with other highly developed trauma systems, the generalizability may be limited by the mixed urban-rural geography and that the helicopter emergency service is integrated into the national health care system and frequently used for interhospital transfer.

Conclusions

In conclusion, several of our findings suggest that patients with moderate-to-severe TBI admitted to ACTHs were managed with continuity of care within the trauma system: as much as 40% of patients admitted to ACTHs were transferred to NTCs; clinically available measures of severe injuries were associated with transfer; and some older adults seemed to be selected for transfer despite advanced age. ACTHs manage a large proportion of isolated moderate-to-severe TBI patients both primarily and definitively, which emphasizes the importance of trained staff in triage decisions and high-quality neurotrauma care in non-neurosurgical hospitals. Addressing the quality of neurotrauma care in ACTHs and whether factors other than those evaluated here are emphasized in these complex transfer decisions needs to be addressed in future research.

List of Abbreviations

ACTH	Acute care trauma hospital
AIS	Abbreviated Injury Scale
ASA-PS	American Society of Anesthesiologists Physical Status
CCU/HDU	Critical care and high-dependency units
CI	Confidence Intervals
edf	Effective degrees of freedom
GAM	Generalized Additive Model
GCS	Glasgow Coma Scale
HISS	Head Injury Severity Scale
IQR	Interquartile Range
NISS	New Injury Severity Score
NTC	Neurotrauma Center
NTR	Norwegian Trauma Registry
OR	Odds Ratio
TBI	Traumatic Brain Injury
TC	Trauma Center
TTA	Trauma Team Activation

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13049-023-01097-7.

Supplementary Material 1

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Authors' contribution

MCØ and EJ contributed to the acquisition of data. MCØ and KT contributed to the data analysis. MCØ, KT, TW, OR, EH, and EJ contributed to the interpretation of the data for the article. MCØ drafted the article. EJ, EH, TW, OR, and KT critically revised the article for intellectual content. All authors made substantial contributions to the conception and design of the work, provided final approval of the version to be published, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors attest to meeting the four ICMJE.org authorship criteria.

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Data Availability

The datasets used during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The NTR operates with a waiver of consent. All patients receive written information about their inclusion in the registry and information about the ability to withdraw registrations. This study was approved by the Oslo University Hospital data protection officer (No. 19/16593). According to Norwegian legislation, approval from an ethics committee is not required for studies of deidentified registry data used for health service research.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Appendix

Supplemental Online Content

To *Care pathways and factors associated with interhospital transfer to neurotrauma centers for patients with isolated moderate-to-severe traumatic brain injury: a population-based study from the Norwegian Trauma Registry*

List of contents:

Suppl. Table 1: Variables extracted from the Norwegian Trauma Registry with details regarding operationalizing.

Variable name	NTR categories	Category operationalization
Age	continuous	N/A
Sex	Male	N/A
	Female	N/A
Preinjury ASA-PS	1-4 (no patients with >4)	Full and dichotomized (1+2, 3+4)
Injury site municipality number	N/A	N/A
Mechanism of injury	1 = Traffic: motor vehicle injury	1-5: Transport-related
	2 = Traffic: motorcycle injury	9: Low-energy fall
	3 = Traffic: bicycle injury	10: High-energy fall
	4 = Traffic: pedestrian	6, 7, 8, 11, 99: Other
	5 = Traffic: other	999 and missing: Missing
	6 = Shot by handgun, shotgun, rifle, other firearm of any dimension	
	7 = Stabbed by knife, sword, dagger, other pointed or sharp object	
	8 = Struck or hit by blunt object	
	9 = Low-energy fall	
	10 = High-energy fall	
	11 = Blast injuries	
	99 = Other	
	999 = Unknown	
Emergency Department GCS	3-15	N/A
Highest level of in-hospital care	1 = Emergency Department	2 = General Ward (no change)
	2 = General Ward	4 and 5 = CCU/HDU
	3 = Operation Theatre	1, 3, 6 = Other
	4 = High Dependency Unit (HDU)	
	5 = Critical Care Unit (CDU)	
	6 = Unknown	
Abbreviated Injury Scale	N/A	N/A
New Injury Severity Score	N/A	N/A
30-day mortality	N/A	N/A

Abbreviations: ASA-PS, American Society of Anesthesiologists physical status; GCS, Glasgow Coma Scale; N/A, Not applicable.

Suppl. Table 2: Categorization of Abbreviated Injury Scale Head codes to pathoanatomic injury types.

Pathoanatomic injury group	Injury category according to AIS manual	Injury codes	Severity code
Skull fracture			
	Skull fractures NFS	150000	2
	Base (basilar) fractures	1502xx	.3-.4
	Vault fractures	1504xx	.2-.4
Vascular injuries			
	Arterial, sinus, and venous injuries	12xxxx	.3-.6
Nerve injuries			
	Cranial nerve injuries	13xxxx	.2-.3
Epidural hematoma			
	Cerebellum epidural hematoma	140414; 140416; 140418; 140422	.2-.5
	Cerebrum epidural hematoma	140630; 140631; 140632; 140634; 140636	.2-.5
Subdural hematoma			
	Cerebellum subdural hematoma	140438; 140440; 140442; 140446	.2-.5
	Cerebral subdural hematoma	14065x	.3-.5
Traumatic SAH			
	Cerebellum tSAH	140466	2
	Cerebrum tSAH	140693; 140694; 140695	.2-.3
Other extra-axial hemorrhage			
	Cerebellum hematoma NFS	140410	3
	Cerebrum hematoma NFS	140629	3
	Cerebellum subpial hemorrhage	140470	2
	Cerebrum subpial hemorrhage	140696; 140697; 140698	.2-.3
Brain stem			
	Brain stem NFS	140299	5
	Brain stem compression, contusion, infarction	14020x	5

	Brain stem hemorrhage, laceration, massive destruction, penetrating, transection	14021x	.5-.6
Brain contusion			
	Cerebellum contusion	14040x	.2-5
	Cerebrum contusion	14060x; 14061x; 140620; 140621; 140622; 140624; 140626	.2-.5
	Intracerebellar hematoma	140426; 140428; 140430; 140434	.2-.5
	Intracerebral hematoma	140638; 140639; 14064x	.2-.5
DAI			
	Cerebrum	140628; 140625; 140627	.4-.5
	Concussive injuries; DAI	161007; 161008; 161011; 161012; 161013	.4-.5
Penetrating			
	Penetrating injury to skull	1160xx	.3-.5
	Cerebellum penetrating	140478; 140477; 140476	.3-.5
	Cerebrum penetrating	140690; 140691; 140692	.3-.5
Other			
	Crush injury	113000	6
	Cerebellum NFS	140499	3
	Cerebellum laceration	140474; 140473; 140472	.3-.4
	Cerebellum brain swelling/edema NFS	140450	3
	Cerebellum infarction (due to traumatic vascular occlusion)	140458	3
	Cerebellum ischemic brain damage direcctly related to head trauma	140462	3

	Cerebrum NFS	140699	3
	Cerebrum laceration	140688; 140687; 140686	.3-.4
	Cerebrum brain swelling NFS	140660; 140662; 140664; 140666	.3-.5
	Cerebrum brain edema NFS	140668; 140670; 140672; 140674	.3-.5
	Cerebrum infarction	140676	3
	Cerebrum intraventricular hemorrhage	140678; 140675; 140677	.2-.4
	Cerebrum ischemic brain damage directly related to trauma	140680; 140681; 140683	.3-.5
	Pneumocephalus directly related to head trauma	140682	3
	Pituitary injury	140799	3
	Concussive injuries	161000; 161001; 161002; 161003; 161004; 161005; 161006	.1-.3
	Scalp injuries	110099; 110202; 11040x; 11060x; 11080x	.1-.3
.9-injuries not included			
	Injuries to the head NFS	100099	9
	Died of head injury without further substantiation of injuries or no autopsy confirmation of specific injuries	100999	9
	Trauma-associated findings not related either to intervention or to anatomically-described head injury NFS	140689	9
	Cerebrum hypoxic or ischemic brain damage secondary to systemic hypoxemia, hypotension or shock not directly related to head trauma	14070x	9

Based on AIS 2005, update 2008
Injury codes including x denote all numbers with that prefix. Severity codes given as ranges reflect all severity codes possible for that injury category.
NFS: Not Further Specified.

Suppl. Table 3: Overview of road distances and drive times between acute care trauma hospitals and corresponding neurotrauma centers in Norway.

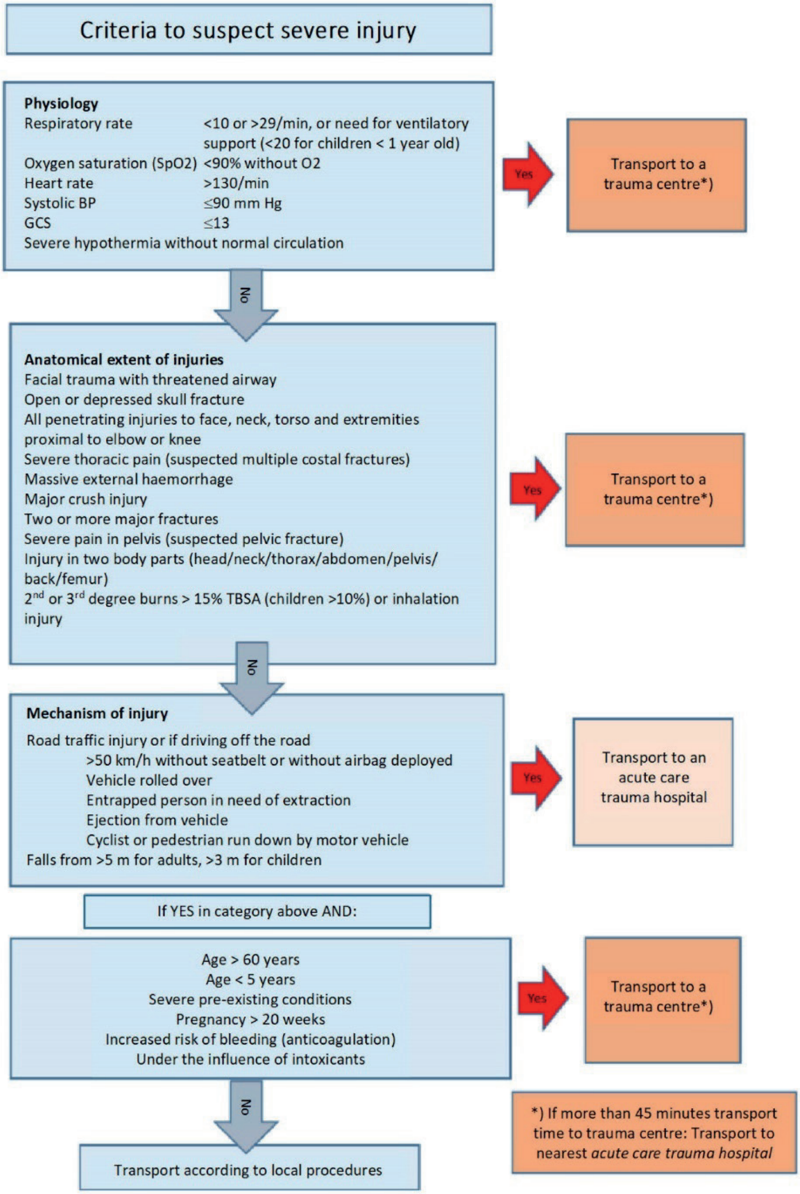
Neurotrauma center (NTC)	Acute care trauma hospital	Distance to regional NTC (km)*	Drive time (hh:mm)*
Haukeland University Hospital	Førde	179	03:16
Haukeland University Hospital	Haugesund	139	03:13
Haukeland University Hospital	Odda	136	02:41
Haukeland University Hospital	Stord	84	02:25
Haukeland University Hospital	Voss	103	01:31
St. Olav University Hospital	Kristiansund	197	03:21
St. Olav University Hospital	Levanger	80	01:09
St. Olav University Hospital	Molde	220	03:40
St. Olav University Hospital	Namsos	195	02:52
St. Olav University Hospital	Volda	347	06:39
St. Olav University Hospital	Ålesund	290	05:26
Stavanger University Hospital	N/A	N/A	N/A
UNN Tromsø	Bodø	538	07:51
UNN Tromsø	Hammerfest	439	08:46
UNN Tromsø	Harstad	303	04:09
UNN Tromsø	Kirkenes	809	10:43
UNN Tromsø	Lofoten	497	06:43
UNN Tromsø	Mo i Rana	658	09:11
UNN Tromsø	Narvik	235	03:15
UNN Tromsø	Sandnessjøen	767	10:49
UNN Tromsø	Vesterålen	409	05:34
Ullevål University Hospital	Ahus	18	00:22
Ullevål University Hospital	Arendal	258	02:59
Ullevål University Hospital	Bærum	16	00:21
Ullevål University Hospital	Drammen	43	00:43
Ullevål University Hospital	Flekkefjord	426	05:11
Ullevål University Hospital	Fredrikstad, Kalnes	90	01:09
Ullevål University Hospital	Gjøvik	123	01:54
Ullevål University Hospital	Hamar	129	01:28
Ullevål University Hospital	Kongsvinger	94	01:20
Ullevål University Hospital	Kristiansand	321	03:41
Ullevål University Hospital	Lillehammer	184	02:08
Ullevål University Hospital	Ringerike	55	01:00
Ullevål University Hospital	Telemark, Skien	135	02:03
Ullevål University Hospital	Tynset	326	04:04
Ullevål University Hospital	Tønsberg	103	01:19

*Distance and drive time estimates according to openstreetmap.org

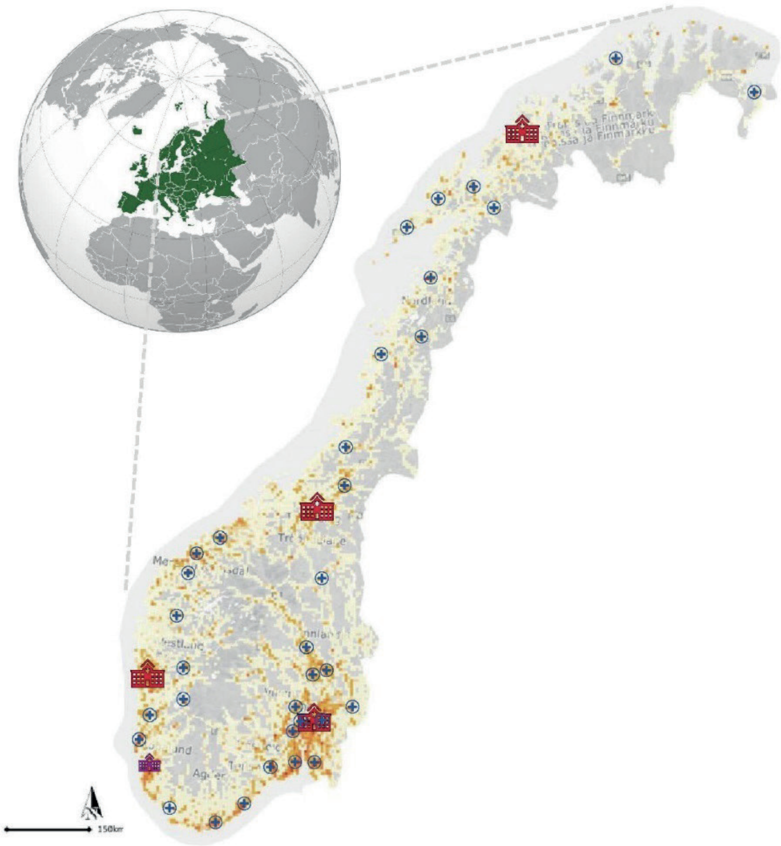
Abbreviations: NTC, Neurotrauma center; UNN, University Hospital of Northern Norway.

Suppl. Table 4: Overview of selected transfer criteria for injuries to the head and CNS, according to the Norwegian Trauma Plan.

- Penetrating injury/open fracture
- Depressed fracture
- Lateralizing signs
- GCS deterioration
- GCS <14 with CT findings
- Spinal injury or unstable spinal/neck fracture

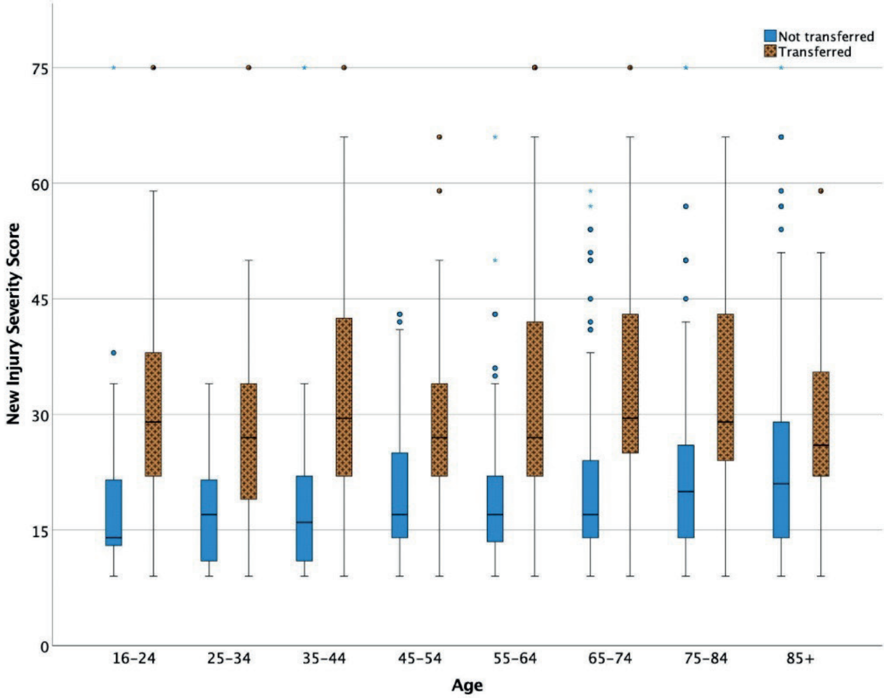


Suppl. Figure 1: The Norwegian trauma field triage criteria.

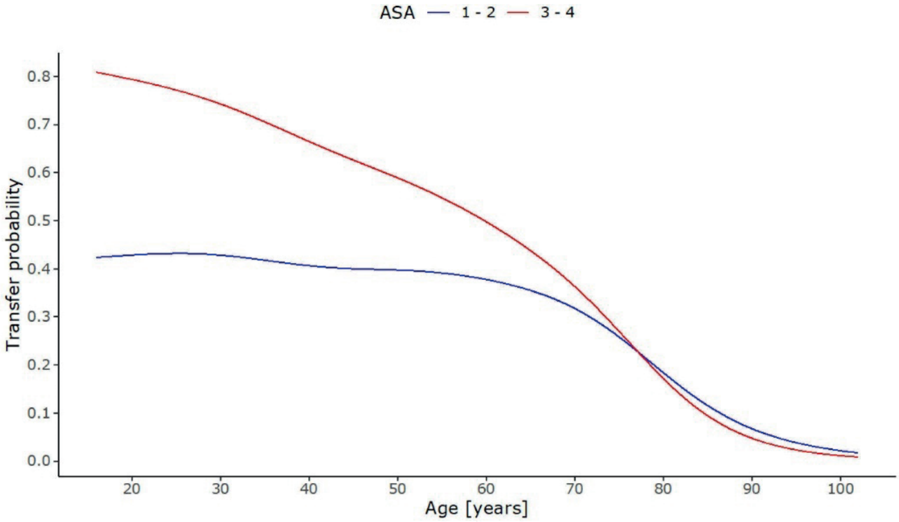


Suppl. Figure 2: Overview of population density and neurotrauma centers and acute care trauma hospitals in Norway.

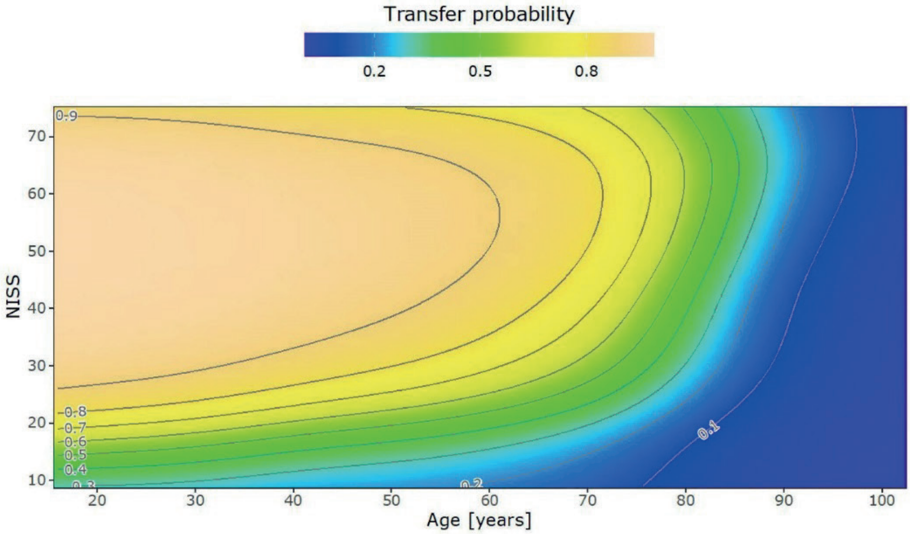
A population density map of Norway with locations of neurotrauma centers (red for regional trauma centers and violet for the one acute care trauma hospital with neurotrauma services) and acute care trauma hospitals (blue) superimposed. Colors from light yellow to orange represent increasing population density. Left: Norway's location in Europe. *Public domain content from Wikimedia Commons and Statistics Norway.*



Suppl. Figure 3: Age-stratified New Injury Severity Score (NISS) distributions for transferred and nontransferred patients.
New Injury Severity Score (NISS) distributions for patients with isolated moderate-to-severe traumatic brain injury primarily admitted to acute care trauma hospitals, comparing nontransferred to transferred patients within age groups. The lower NISS range at 9 reflects the study inclusion criteria. Circles symbolize outliers and asterisks extreme outliers.



Suppl. Figure 4: Transfer probability by age and preinjury ASA-PS.
The probability of interhospital transfer for patients with isolated moderate-to-severe traumatic brain injury, comparing patients with preinjury American Society of Anesthesiologists physical status scores (ASA-PS) 1-2 with 3-4.



Suppl. Figure 5: Transfer probability by age, NISS, and preinjury ASA-PS 3-4. Contour plot showing the estimated probability for interhospital transfer as NISS and patient age changes for patients with preinjury comorbidity according to the American Society of Anesthesiologists physical status score (ASA-PS) 3-4, as a function of the full generalized additive model. Other covariates are fixed at their median and mode values for continuous and categorical data, respectively. For comparison with ASA-PS 1-2 patients, see figure 5A.

10.4 Paper IV

Decision-making in interhospital transfer of traumatic brain injury patients: exploring the perspectives of surgeons at general hospitals and neurosurgeons at neurotrauma centres

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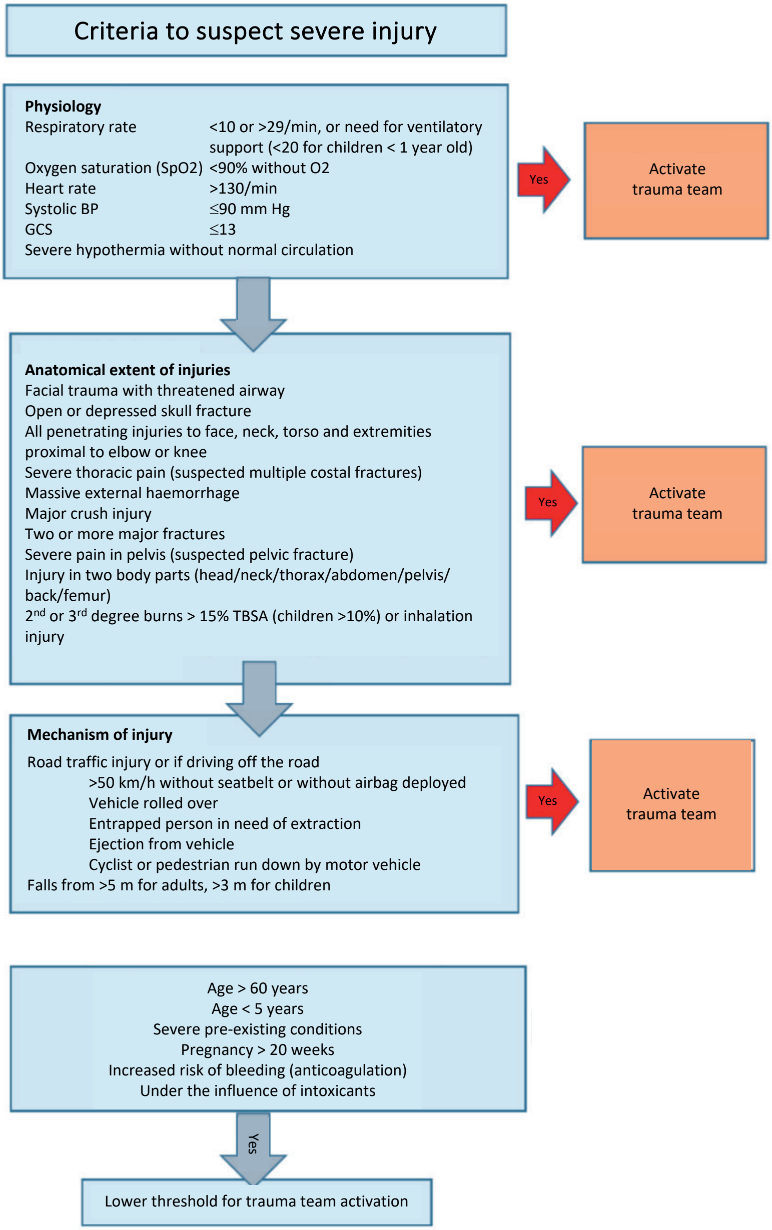
Conflicts of interest: The authors have no competing interests to declare.

Word count: 4971 words

Keywords: Traumatic Brain Injury, interhospital, transfer, elderly, old, geriatric, frailty, comorbidity, functional impairment, qualitative study

11 Appendices

11.1 Appendix 1



Appendix 1: Norwegian field triage and trauma team activation criteria. Reused with permission from the Norwegian National Advisory Unit on Trauma.

11.2 Appendix 2

34 Skade – mulig alvorlig / omfattende

Andre aktuelle oppslag:
05 Stor hendelse / masseskadehendelse
10 Brannskade / skoldeskade / elektrisk skade
24 Kjemikalier / gasser / CBRNE (ulykke med farlig gods)
33 Skade – brudd / sår / småskader
35 Trafikkskade

		KRITERIER	
RØD – akutt	A.34.01	**Possible serious injury, one or more people involved, detailed information not immediately available**	3–9
RØD – akutt	A.34.02	**Possible serious, life threatening injury:** a. Unresponsive Gå til 01 / 02 / 03 Bevisstløs voksen / barn b. Breathing problems c. Has been unconscious / semiconscious / dazed / feels very faint or dizzy d. Major blood loss, still bleeding e. Pale and clammy skin f. Severe hypothermia Se 23 Hypotermi	3–9
RØD – akutt	A.34.03	**Possible serious injury – visible injury / fracture / burns:** a. Facial injury (NB! Possible threat to airway) b. Major open wound c. Open wound – knifing / wounds from a weapon d. Major external bleeding e. Major crush injury / injuries in 2 or more parts of the body f. Severe pain in the chest – suspect extensive fractures of the ribs g. Suspect 2 or more major fractures h. Severe pain in the pelvis, possible pelvic fracture i. Possible fracture of the spine with paralysis j. Partial / full thickness burns – adults > 15 % / child > 10 % of the body; or inhalation injury Se 10 Brannskade / skoldeskade / elektrisk skade	3–9
RØD – akutt	A.34.04	**Possible serious injury due to mechanism of injury:** a. Cycle / skateboard / horse (e.g. collision, driving off the road at speed, cycle accident) b. Fall over 5 metres (adult), over 3 metres (child) c. Accident involving motor vehicle Gå til 35 Trafikkskade	3–9
RØD – akutt	A.34.05	**Possible serious injury and complicating factors:** a. Over 60 yrs b. Under 5 yrs c. Has a serious medical condition d. Over 20 weeks pregnant e. Increased danger of bleeding, is on anticoagulants f. Intoxicated	3–9
GUL – haster	H.34.01	**Has been unconscious – awake and completely alert now**	4
GUL – haster	H.34.02	**Blow to the head – remembers little about the incident / nauseous / dizzy**	4
GUL – haster	H.34.03	**Neck pain, nauseous or dizzy**	6
GUL – haster	H.34.04	**Severe pain / deformity (possible fracture / joint injury) in the face, shoulder, arm, hand, neck of femur, knee, lower leg, ankle, sole of the foot**	8
GUL – haster	H.34.05	**Bleeding that has stopped or can be stopped**	5
GUL – haster	H.34.06	**Fall over 3–5 metres**	78
GUL – haster	H.34.07	**Child fall > 3 metres – seems unhurt**	78
GUL – haster	H.34.08	**Other urgent symptoms related to this page**	
GRØNN	V.34.01	**Other, not urgent** Gå til 33 Skade – brudd / sår / småskader	

RESPONS

RØD – akutt

AMK
1. Varsle ambulanse(r) og LV-lege / LVS.
2. Trippelvarsling hvis relevant.
3. Vurder også å varsle:
   - Akutthjelper
   - Luftambulanse / legespesialist
   - Andre nødetater
   - AMK-lege
   - **Regionalt traumesenter**
4. Vurder pasienttransport i privatbil.
5. Vurder resterende kriterier.
6. Sjekk kjernejournal (KJ) dersom kritisk informasjon.
7. Gi relevante råd / instruksjoner.
8. Hold forbindelsen med innringer, ev. be innringer ta ny kontakt ved behov.
9. Overvåk aksjonen og oppdater alle involverte.
10. Oppdater involverte om ev. sikkerhetsrisiko.

LVS
1. Opprett konferanse med AMK, som overtar samtalen og iverksetter riktig respons.
2. Bistå AMK med lokalkunnskap.
3. Oppdater LV-legen.
4. Varsle etter kommunal beredskapsplan ved behov.
5. Oppdater involverte om ev. sikkerhetsrisiko.

GUL – haster

AMK
1. Send ambulanse **hvis klart behov** og:
   - Still relevante tilleggsspørsmål
   - Gi relevante råd
   - Informer LVS / LV-lege
   - Be innringer ta ny kontakt ved forverring
2. Informer LVS / LV-lege, alt. opprett konferanse på forhåndsdefinert linje.
3. Oppdater involverte om ev. sikkerhetsrisiko.

LVS
1. Vurder resterende kriterier og still relevante tilleggsspørsmål.
2. Gi relevante råd.
3. Kontakt AMK ved behov for ambulanse.
4. Gjør ett av følgende tiltak iht. lokal instruks:
   - Konferer med lege, ev. opprett konferanse mellom pas. og LV-lege / fastlege
   - Be pas. komme til LV
   - Avtal annen transport
5. Be innringer ta ny kontakt ved behov.
6. Oppdater involverte om ev. sikkerhetsrisiko.

GRØNN

AMK / LVS
Gå til 33 Skade – brudd / sår / småskader

☐ LOKAL TILPASNING FORELIGGER **34**

ADDITIONAL QUESTIONS

Are there any other children / adolescents present? Are they in need of immediate care and support?

THE PRESENT SITUATION

- *What has happened and when did it happen?*
- *How many casualties?*
- *If fall from a heght – how high? What did the casualty land on? Surface?*
- *If the accident happened outdoors: What is the weather like? Visibility? Is it possible to drive all the way to the incident? Been lying outdoors for long? Cold? Danger of hypothermia?*
- *Are there others present with similar symptoms?*

ABOUT THE CASUALTIES

- *Describe the injuries / casualties*
- *Altered level of response? Unresponsive?*
- *Breathing problems?*
- *External bleeding? Bleeding a lot?*
- *Visible injuries: wounds, fractures, deformities?*
- *Problems moving arms / legs?*
- *In pain? Where?*
- *Any information about a possible fainting fit before the accident?*

HODESKADE PÅ BARN UNDER ETT ÅR

Sykehusinnleggelse og lav terskel for å oppgradere til rød respons.

DESTINASJONSKRITERIER I FØLGE NASJONAL TRAUMEPLAN (www.traumeplan.no)

Pasienter som skal til traumesenter:

- **Et eller flere oppfylte kriterier fra A.34.02 fysiologisk påvirkning og / eller A.34.03 anatomisk skadeomfang.**
- **Oppfylt kriterium i A.34.04 skademekanisme OG samtidig kriterium i A.34.05 kompliserende tilstander**

Pasienter som skal til nærmeste sykehus med traumefunksjon:

- **Kun oppfylt kriterium fra A.34.04 skademekanisme**

Dersom det er mer enn 45 minutters transporttid til traumesenter, transporteres en pasient som er fysiologisk påvirket til nærmeste akuttsykehus med traumefunksjon.

Dersom pas. ved ankomst til akuttsykehus med traumefunksjon viser seg å oppfylle kriteriene for alvorlig skade, skal det tas kontakt med traumeleder ved traumesenter.

OM SKADE – MULIG ALVORLIG / OMFATTENDE

ALVORLIGHETSGRAD

Vurderes ut fra opplysninger om:

- Fysiologisk påvirkning / symptomer og tegn / vitale funksjoner
- Anatomisk skadeomfang
- Skademekanisme
- Andre tilstander/faktorer som øker risikoen for alvorlig skade

Den alvorlig skadde pasient er i en dynamisk situasjon, der fysiologi kan endres rask. Mistanken om at en person er alvorlig skadd baseres på all tilgjengelig viten – men fordi slike skader må transporteres og behandles raskt, må beslutning om å anse pas. for alvorlig skadd treffes før alle fakta er kjente. Alle traumesystemer aksepterer derfor en viss grad av overtriage.

UNNGÅ NEDKJØLING AV PAS.

Nedkjøling øker dødeligheten og kan gi økt blødningstendens og infeksjonsfare, forlenget sykehusopphold og dårligere prognose.

SKADET KROPPSDEL

Hodeskade. Like etter skaden kan det være vanskelig å skille mellom en hjernerystelse (kortvarig bevissthetstap etterfulgt av gradvis oppvåkning), og en mer alvorlig skade. Bevissthetsnivået er det viktigste kliniske tegnet til å følge utviklingen.

Tegn på alvorlig skade:

- Bevisstløs i mer enn 5 min.
- Fallende bevissthet etter forbigående oppvåkning
- Kramper etter hodeskade
- Lammelse (nedsatt bevegelighet i armer/ben)

Dette kan skyldes blødning i hjernen (intracerebral blødning) eller utenpå hjernen (epiduralt/subduralt hematom) som er livstruende. Ved sirkulasjonssvikt skal man mistenke andre indre blødninger fordi blodtapet ved hodeskade alene sjelden blir så stort.

Skade i ansikt, kjeve eller hals som helt eller delvis stenger luftveiene er livstruende. Skader på halsens blodårer kan raskt gi livstruende blødninger. Mistenk samtidig alvorlig hodeskade ved stor ansiktsskade.

Nakke- og ryggskade. Mistenk nakke / ryggskade ved samtidig hodeskade, spesielt hvis pas. er bevisstløs og ikke kan si fra om lammelser, sensibilitetstap eller smerter i nakken / ryggen. Respirasjonsmusklene kan lammes helt eller delvis ved nakkebrudd. Lammelser i det autonome nervesystem kan gi lavt blodtrykk (nevrogen sirkulasjonssvikt). Tverrsnittslesjoner (avrivninger av ryggmargen) kan forverres ved ukyndig behandling og unødig flytting av pas. Hvis pas. likevel må flyttes, skal hodet holdes helt stabilt, i nøytral posisjon forhold til kroppen.

Skade i brystkassen kan være livstruende hvis lunger, hjerte eller store blodkar rammes. Slike skader har derfor høy prioritet fordi tilstanden raskt kan bli verre. Pustevansker og økt respirasjonsfrekvens er alvorlige symptomer.

Bukskade. Så vel stumpe traumer som penetrerende skader kan gi stor blødning til kroppens hulrom fra indre organer. Magesmerter kan gi mistanke om slik blødning, men det kan ta noe tid fra skaden skjer til pas. får sirkulasjonssvikt.

Bekkenbrudd og lårbensbrudd kan gi store indre blødninger og sirkulasjonssvikt. Tidlig bruddstabilisering er viktig.

Knusning eller penetrerende skade i hals, bryst, buk og lår kan gi stor indre eller ytre blødning som ikke alltid lar seg stoppe, selv ved direkte trykk mot såret. Rask kirurgisk behandling kan være livreddende.

Ytre blødninger / avriving av legemsdel. Blødninger stanses ved direkte trykk mot det blødende sted. Tourniqet skal kun benyttes av personell med særskilt opplæring. Den avrevne legemsdelen kan legges i en ren plastpose, helst med sterile saltvannskompresser rundt. Nedkjøling anbefales normalt ikke. Konferer ev. med traumeleder ved mottakende sykehus ved lang transporttid.

Mindre skader. Armbrudd, benbrudd nedenfor knærne, lårhalsbrudd og kutt hvor blødningen har stanset, gir sjelden akutte komplikasjoner hvis det er eneste skade.

Se 33 Skade – brudd / sår / småskader

ADVICE

Hvis pas. er bevisstløs og ikke puster normalt – start HLR-instruksjon fra 01 / 02 Bevisstløs voksen / barn – puster ikke normalt.

A. GENERAL ADVICE AND INFORMATION

1. RED KRITERIA and when relevant

- *Help is on its way. Keep this phone handy until the medics arrive.*
- *Comfort and reassure the casualty.*
- *Someone must keep an eye on the casualty at all times. Let me know immediately if s/he worsens.*

If the casualty is outdoors:

- *Avoid any loss of body heat, cover the pat. with blankets and place on an insulating layer if possible. Find shelter and shield from the wind.*

2. MAKE THE AREA SAFE

- *If possible and without risk, get the casualty to safety.*
- *Keep yourself and others out of danger at all times.*
- *Do not move the casualty unless it is absolutely necessary for the safety and warmth of the pat.*
- *Try to get an overall picture and get back to me immediately.*

B. FIRST AID AND OTHER ADVICE

3. BREATHING PROBLEMS

- *Try to create calm around the casualty, loosen tight clothing.*
- *Help the casualty to sit up / find a comfortable position.*
- *Monitor breathing.*

If the casualty can't sit up:

- *Help the casualty to lie down on his/her side.*
- *Gently tilt the head back and lift the chin forwards.*

Infant under 1 year:

- *Keep the head in a neutral position and lift the chin forwards.*
- *Monitor breathing, tell me if there is any change.*

4. ALTERED LEVEL OF RESPONSE / PALE AND CLAMMY SKIN / UNWELL OR NAUSEOUS

- *Help the pat. to lie down on his/her side, preferably in the recovery position.*
- *Make sure s/he can breathe freely.*
- *Avoid any heat loss / cooling down.*

5. MAJOR BLEEDING / OPEN WOUNDS

- *Stop the bleeding by applying presssure with a dry cloth to the wound until the bleeding stops.*
- *If possible keep the wounded area raised.*
- *Cover the wound with clean cloths or bandages.*

6. POSSIBLE NECK INJURY

- *Prevent any further damage of a possible neck injury, especially if the casualty is unresponsive / complains of neck pain or numbness.*
- *Support the head and keep it in a striaght line with the body.*

If the casualty has to be moved:

- *Keep the casualty completely stable and in line with the body, without moving the neck.*
- *Maintain a free airway and check s/he can breathe freely.*

7. CASUALTY WITH MAJOR INJURIES who may need an operation / anaesthetic

- *Do not allow the casualty to eat or drink.*

8. FRACTURES

- *Stabilise the injured area.*
- *Fractured legs can be stabilised by supporting the fractured area with clothes, blankets or cushions / pillows.*
- *OPEN FRACTURE: Avoid contamination of the wound. Place clean cloths / bandages over the injured area.*

9. AMPUTATION

- *Apply pressure to the area that is bleeding, do not use a tourniquet unless qualified to do so.*
- *Place the severed limb in a clean plastic bag. If you have sterile saline compresses wrap them round the severed limb.*
- *It is not normally necessary to cool it.*

Konferer ev. med kirurg / traumeleder ved lang transporttid.

Appendix 2: Extract from the Norwegian Index for Medical Emergencies. Reused with permission from NAKOS.