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Focus on traumatic brain and cerebrovascular injuries

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To my family.

UNIVERSITY OF TURKU
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ABSTRACT

The prognosis of patients with facial fractures is influenced by multiple factors that need to be recognized at an early stage. Associated injuries are common, and they may delay the management of facial fractures. Conversely, significant associated injuries may remain undetected unless systematic multidisciplinary trauma diagnostics are applied.

The aim of this thesis was to investigate the prevalence and risk factors for associated injuries in patients with facial fractures, focusing particularly on traumatic brain injuries (TBI) and blunt cerebrovascular injuries (BCVI). The primary objective was to identify predictors that worsen prognosis and increase mortality. The thesis is based on four registry studies of patients treated at Helsinki University Hospital between 2013 and 2018.

The first study assessed the prevalence of associated injuries and compared differences between adult and elderly patients. The second examined the incidence and risk factors of BCVI in patients with craniofacial fractures. The third focused on the occurrence and risk factors for TBI in facial fracture patients. The fourth study evaluated diagnostic delay in TBI and the risk factors contributing to such delays among facial fracture patients.

Associated injuries were found to be frequent, with TBI being the most common. Cranial fractures and neck injuries were strongly associated with an increased risk of TBI. High-energy trauma significantly elevated the risk of both TBI and BCVI, yet severe associated injuries were also observed following low-energy mechanisms and minor fractures. Elderly patients had a notably higher risk of associated injuries, which were more severe and carried greater mortality. Elderly persons more often experienced diagnostic delay with regard to associated TBI.

The findings of this thesis highlight the importance of developing care pathways that ensure facial fracture patients are evaluated in settings where multidisciplinary trauma diagnostics and treatment are available. Careful exclusion of associated injuries and structured follow-up routines are essential. Particular attention should be given to elderly patients, as they present with a higher prevalence of associated injuries, more severe outcomes, and greater diagnostic challenges

KEYWORDS: Facial fracture, Associated injury, Traumatic brain injury, Blunt cerebrovascular injury, Cranial fracture

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TIIVISTELMÄ

Kasvovammapotilaiden hoidon ennuste riippuu useista tekijöistä, jotka tulee tunnistaa varhaisessa vaiheessa. Oheisvammat ovat yleisiä ja voivat viivästyttää kasvomurtuman hoitoa. Toisaalta merkittäviä vammoja voi jäädä diagnosoimatta ilman moniammatillista traumadiagnostiikkaa.

Tutkimuksen tavoitteena oli selvittää kasvomurtumapotilaiden oheisvammojen esiintyvyyttä ja riskitekijöitä, erityisesti aivovammojen ja tylppien kaulasuonivammojen osalta, sekä tunnistaa ennustetta heikentäviä ja mortaliteettia lisääviä tekijöitä. Väitöskirja koostuu neljästä rekisteritutkimuksesta, joissa tarkasteltiin vuosina 2013–2018 Helsingin yliopistollisessa keskussairaalassa hoidettuja potilaita.

Ensimmäisessä osatyössä selvitettiin oheisvammojen esiintyvyyttä kasvomurtumapotilailla ja eroja aikuis- ja vanhuspotilailla. Toisessa tutkittiin tylppien kaulasuonivammojen esiintyvyyttä ja riskitekijöitä kallo- ja kasvomurtumapotilailla. Kolmannessa tarkasteltiin kasvomurtumien yhteydessä aiheutuvien aivovammojen esiintyvyyttä ja riskitekijöitä. Neljännessä analysoitiin kasvomurtumapotilaiden viivettä aivovammojen diagnostiikassa sekä viiveeseen liittyviä riskitekijöitä.

Oheisvammat olivat yleisiä ja aivovammat korostuivat näiden joukossa. Kallomurtumat ja kaulan alueen vammat lisäsivät aivovamman riskiä, ja korkea-energinen vammamekanismi suurensi sekä aivo- että kaulasuonivammojen riskiä. Vakavia vammoja todettiin kuitenkin myös matalaenergisten vammamekanismien ja yksinkertaisten kasvomurtumien yhteydessä. Vanhuksilla oheisvammoja esiintyi enemmän, ne olivat vakavampia ja niihin liittyi korkeampi kuolleisuus sekä suurempi riski oheisaivovamman diagnostiikkaviiveelle.

Tulokset tukevat hoitopolkujen kehittämistä siten, että kasvomurtumapotilaat tutkitaan moniammatillisessa traumayksikössä, jossa oheisvammat voidaan systemaattisesti poissulkea ja seuranta varmistaa. Erityistä huomiota tulee kiinnittää vanhuksiin, joilla oheisvammojen esiintyvyys, vakavuus ja diagnostiikan haasteet korostuvat.

AVAINSANAT: Kasvomurtuma, Liitännäisvamma, Traumaattinen aivovamma, Tylppä kaulasuonivamma, Kallomurtuma.

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Abbreviations

AI	associated injury
AIS	abbreviated injury scale
BCVI	blunt cerebrovascular injury
CI	confidence interval
CT	computed tomography
CTA	computed tomography angiography
DAI	diffuse axonal injury
FFSS	facial fracture severity score
FISS	facial injury severity scale
GCS	Glasgow coma scale
ISS	injury severity score
ICA	internal carotid artery
ICISS	ICD-based injury severity score
ICP	intracranial pressure
IMH	intramural hematoma
MFISS	maxillofacial injury severity score
MRI	magnetic resonance imaging
mTBId	missed traumatic brain injury diagnosis
NISS	new injury severity score
NOE	naso-orbito-ethmoid
OR	odds ratio
RR	risk ratio
TBI	traumatic brain injury
TRISS	trauma and injury severity score
VA	vertebral artery

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

I Kokko L-L, Puolakkainen T, Suominen A, Snäll J, Thorén H. Are the elderly with maxillofacial injuries at increased risk of associated injuries? *J Oral Maxillofac Surg*, 2022; 80: 1354–1360.
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II Puolakkainen T, Vähäsilta L-L, Bensch F, Narjus-Sterba M, Wilson M.L, Thorén H, Snäll J. Blunt cerebrovascular injuries in the craniofacial population – Are we screening the right patients?. *Int J. Oral Maxillofac Surg*, 2021, 50: 463–470 .
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III Kokko L-L, Snäll J, Puolakkainen T, Piippo-Karjalainen A, Suominen A, Thorén H. Concomitant head or neck injury increases risk of traumatic brain injury in facial fracture patients. *Br J.Oral Maxillofacial Surg*, 2024; 62: 704–709.
https://doi.org/10.1016/j.bjoms.2024.04.011

IV Kokko L-L, Puolakkainen T, Thorén H, Piippo-Karjalainen A, Suominen AL, Snäll J. Traumatic brain injury in patients with facial fracture – a challenge for the clinician? *J Stomatol Oral Maxillofac Surg*, *2025; 126*
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1 Introduction

Trauma is the single most common cause of death and disability among the working age population worldwide each year. Approximately six million deaths are due to trauma, with 40 million people being permanently disabled every year (Annual deaths from the WHO Global Health Observatory 2018, Debas et al., 2015; Wesson et al., 2014).

Facial fractures potentially affect many important daily functions, such as sense of smell, vision, eating, speaking, hearing and breathing. In addition, the face is a significant part of an individual´s appearance and personality. Facial fractures usually have a substantial impact on the patient´s quality of life and at worst, facial fractures and related injuries cause permanent disability or are fatal. Patients with facial injuries form a diverse group, whose injuries vary from mild soft tissue injuries to severe panfacial fractures. Treatment needed ranges from observation to complex surgical corrections and long hospital and intensive care periods. The proportion of patients with facial fractures among trauma patients varies between studies and population groups, but facial fractures are a substantial part of traumatic injuries. According to estimates, facial fractures occur in 15-34% of major trauma patients (Bocchialini and Castellani, 2019). Facial fracture patients also frequently have associated injuries (AIs) in other parts of the body (Béogo et al., 2013; Ghosh and Gopalkrishnan, 2023; Thorén et al., 2010).

The characteristics of facial fractures vary between younger adults and elderly patients (Kloss et al., 2007). Polypharmacy, age-related physiological changes and comorbidities among others, expose the elderly to different types of injuries and injury mechanisms when compared to younger adults. The previous literature shows that mortality associated with trauma is significantly greater in the elderly when compared to younger adults (Herron et al., 2017). In addition, the elderly emergency patients are reported to be commonly undertriaged and prone to diagnostic errors (Kodadek et al., 2015). As the population ages and life expectancy increases, the proportion of elderly trauma patients among those exposed to trauma, is likely to increase. The differences between younger age groups and elderly patients need to be identified and taken into account when evaluating facial fracture patients and the

difference in AI patterns between younger adults and elderly patients should be further emphasized.

The prognosis for the treatment of patients with facial fractures depends on several factors that should be identified in the early stages of treatment. A severe AI can cause delay in the treatment of facial fracture. On the other hand, a patient with a facial fracture can have serious complications, if the possible AIs are not taken into account early on. Among the most potentially severe AIs in facial fracture patients are traumatic brain injuries (TBIs) and blunt cerebrovascular injuries (BCVIs). Both of these potentially have significant long-term sequalae and can cause major disabilities or death if not diagnosed and treated promptly. Hence, there is a need to further underline the frequency and investigate the types and risk factors for AIs of facial fracture patients to reduce the risk of overlooking these injuries and to highlight the need for multiprofessional care of these patients.

This thesis aimed to report and compare the demographic context and risk factors for AIs in adult and elderly facial fracture patients. The aim was also to particularly clarify occurrence and clinical predictors for TBIs and BCVIs in facial fracture patients. Additionally, the study aimed to investigate the frequency and clinical predictors associated with the diagnostic delay of TBI in conjunction with facial fractures.

2 Review of the Literature

2.1 Overview of facial fractures

2.1.1 Anatomical distribution

The facial skeleton, also referred to as the viscerocranium, is a complex anatomical structure composed of multiple bones that collectively form the structural framework of the human face. These bones include the frontal, sphenoid, ethmoid, zygomatic, lacrimal, vomer, palatine and nasal bones, in addition with the maxilla and mandible (Netter, 2011). Together, they establish both the architectural integrity and the functional foundation for key facial features such as the orbits, nasal cavity, maxillary sinuses and oral cavity.

For clinical and anatomical purposes, particularly in the context of trauma assessment and surgical planning, the facial skeleton can be divided to three horizontal segments or "thirds". This classification aids in the systematic evaluation and localization of facial fractures, as illustrated in Figure 1. The upper facial third comprises of the frontal bone, including the orbital roofs. 2. The middle facial third (the midface) comprises of the maxilla, zygomatic bone, nasal bone and medial and inferior orbital walls. 3.The lower facial third comprises of the mandible. (Pappachan and Alexander, 2012).

To further classify the solitary injuries, facial fractures can be divided to 1. upper third fracture (i.e., fractures of the orbital roof, frontal sinus, anterior skull base or a combination of these), 2. midfacial fracture (i.e., orbital fracture, zygomatico-orbital fracture, nasal fracture, maxillar fracture or extended midfacial fracture (i.e., LeFort I-III, naso-orbito-ethmoidal (NOE) or a combination of midfacial fractures), 3. mandibular fracture (i.e., condylar fracture, fracture of the ascending ramus, fracture of the angle, fracture of the body of the mandible, fracture of the coronoid process or a combination of these) and 4. combined fracture (i.e., mandibular + midfacial fracture, midfacial + upper third fracture or panfacial fracture extending to all facial thirds).

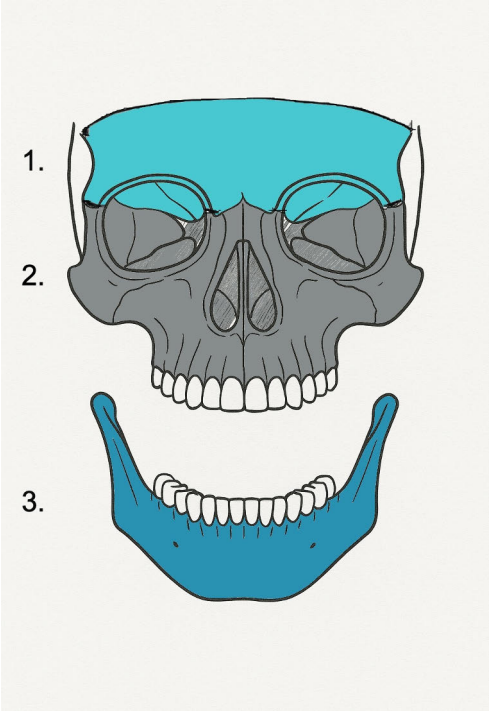

Figure 1. Anatomical thirds of the facial skeleton: 1. The upper facial third, 2. The middle facial third, 3. The lower facial third (Own drawing, generated partly by Chat GPT, Chat GPT, July 15, 2025, OpenAI).

Mandibular fracture is the most common facial fracture, comprising of 23-63 % of facial fractures. Other common fracture types are isolated nasal fractures and fractures of the zygomatico-orbital complex (Boffano et al., 2015b; Bonavolontà et al., 2017; Jarab and Bataineh, 2022; Juncar et al., 2021; Khan et al., 2022; Kostakis et al., 2012; Rose et al., 2021; Wusiman et al., 2020). In the elderly population, fractures of the midface, particularly fractures of the zygomatico-orbital complex, are most common (Brucoli et al., 2020; Irgebay et al., 2022; Toivari et al., 2014).

2.1.2 Sex and age distribution

According to the literature, the proportion of males among trauma patients is significantly higher than that of females (Liu et al., 2024). As with trauma patients in general, the majority of facial fracture patients are also male. The male to female ratio of facial fracture patients ranges between 2:1 to 8:1 (Boffano et al., 2015b; Gandhi et al., 2011; Kraft et al., 2012; Mijiti et al., 2014). The peak incidence of facial fractures is during 20-30 years of age (Naveen Shankar et al., 2012). However,

several studies have showed an increased rate of elderly facial fracture patients reflecting the progressive aging of the Western world´s population. Compared to the younger age groups, where men are overpresented, in the older age groups a higher proportion of facial fracture patients are female (Kloss et al., 2007; Lee, 2012; Yamamoto et al., 2011).

2.1.3 Etiology

The etiology of facial fractures varies greatly depending on several factors, such as geographic location, cultural background and socioeconomic status (Gandhi et al., 2011; Kostakis et al., 2012; Lee, 2012). Facial fractures can occur for several reasons, including road traffic accidents (RTA), assaults, falls, bicycle accidents, sports related injuries and industrial injuries. Worldwide, the leading cause of facial fractures remains RTAs, whereas in the western world, particularly in Europe and Northern America this has been a decreasing trend (Boffano et al., 2015b, 2015a; Zhou et al., 2013). In these countries assaults and falls have become the most important reasons for facial fractures, probably due to the decrease in RTAs because of better quality of roads, higher technical standard for vehicles, stricter traffic regulations and more advanced safety equipment such as helmets, airbags and seat belts (Boffano et al., 2015b; Erdmann et al., 2008; Rashid et al., 2013). Assaults, which have a frequent association with alcohol or drug abuse, particularly among young males, have traditionally been the most common cause of facial fractures in Finland and also in many other Western countries (Allareddy et al., 2011; Thorén et al., 2010; Van Den Bergh et al., 2011). In elderly patients, falls dominate as the main cause of facial fractures. The progressive aging of populations in western countries probably plays a role in the increase of falls as an important etiological factor in facial fracture occurrence (Boffano et al., 2015b; Kloss et al., 2007; Lee, 2012; Yamamoto et al., 2011).

2.1.4 Assessment of severity

Presented in the literature are several trauma scoring systems specifically designed for maxillofacial trauma. The purpose of these systems is to provide accurate assessment of the injury type and among other things, aid to evaluate the prognosis, possible treatment outcome and length of hospital stay. However, a widely accepted system providing a sufficiently accurate description of the severity of the maxillofacial injuries does not appear to be in uniform use, which complicates research on the topic.

The first trauma scoring system for facial trauma was introduced in 1989 by Cooter and David (Cooter and David, 1989). The simple fracture coding system

divided the craniofacial region bilaterally to ten major anatomic zones, which were each distributed to minor zones. The zones were assigned an alpha code and the fracture severity was then coded with a numerical score. The system was, however, criticized for potentially underscoring, since the number of fractures was limited to five for individual major zones. In addition, the concern was, that inclusion of the cranial component in the scoring system would lead to understating the maxillofacial area.

In 2006, Bagheri et al. presented a Facial Injury Severity Scale (FISS) aiming to assist a trauma team to evaluate the severity of facial injuries in a patient. To score the bony injuries, FISS divides the face into horizontal thirds (mandible, mid-face and upper face). In addition, length of the soft tissue laceration is included. However, the mechanism or extent of the soft tissue injury is not included. The system uses fixed weighted scoring scale for the fractures to eliminate user bias, but the weighted scores do not differentiate non-displaced, displaced or for example comminuted fractures to fully evaluate the complexity of the fractures. (Ahmad et al., 2012). FISS does not provide help in determining the treatment modality and although significantly associated with the length of the hospital stay, a study by Bagheri et al. concluded that the system does not predict the length of stay very well (Bagheri et al., 2006).

The maxillofacial injury severity score (MFISS) introduced in 2006 by Zhang et al., utilizes the pre-existing Abbreviated Injury Scale 1990 (AIS-90), selecting the three highest maxillofacial injury severity scores according to the AIS-90. These are then summed to three functional parameters; malocclusion, limited mouth opening and facial deformity. A significant correlation between MFISS and cost of treatment and length of hospital stay was reported (Zhang et al., 2006). Shortcomings of the system that have been reported include the inability to retrospectively obtain the functional parameters, and the lack of ability to account for all patterns of facial trauma (Ahmad et al., 2012).

In 2010, Catapano et al. established the facial fracture severity score (FFSS) assigning numerical grades from 0 to 3 for injuries at 41 different maxillofacial anatomical sites. The grades were determined according to presence of fracture, degree of displacement and bone loss. (Catapano et al., 2010). To simplify the scoring of the fractures, a color coded facial skeletal map was established, and this was found to be intuitive and beneficial (Ahmad et al., 2012).

2.2 Associated injuries (AIs) in patients with facial fractures

2.2.1 Overview of facial fracture associated injuries

AIs are relatively common in patients with facial fractures. The incidence of AIs in connection with facial fractures varies somewhat in the literature, depending on the inclusion criteria of the study and the definition of AI. In previous studies, AIs occur in 11.3-99.3 % of facial fracture patients (Fischer et al., 2001; Follmar et al., 2007; Lim et al., 1993; Thorén et al., 2010; Wusiman et al., 2020).

AIs can occur in single or several organ systems, including the brain, cranial bones, neck, upper or lower extremities, chest, spine and abdomen. According to the literature, brain injuries and limb injuries are among the most common associated injuries in patients with facial fractures (Alvi et al., 2003; Lim et al., 1993; Patil et al., 2018; Thorén et al., 2010).

Some 6% of facial fracture patients present with life-threatening associated injuries, most commonly brain injury, airway compromise or massive hemorrhage (Tung et al., 2000). High energy trauma mechanisms, such as MVAs or falls from height are most likely to cause life-threatening injuries affecting several organ systems. The high energy traumas are the ones where it is important to first and foremost suspect and seek AIs in facial fracture patients also (Thorén et al., 2010; Wusiman et al., 2020).

2.2.1.1 Severity and scoring of traumatic injuries

To improve the quality of care for trauma patients, several different scoring systems have been developed. These tools aim to assess the severity and life-threatening potential of injuries, standardize data collection in healthcare and facilitate research in the trauma field. Originally developed in the 1970s for the study of automobile-related injuries, the first system to measure the severity of injuries was the Abbreviated Injury Scale (AIS) ("Rating the Severity of Tissue Damage," 1971), assigning a severity score to individual injuries. Because of the lack of ability to measure the overall severity of multiple injuries, other scoring systems using the AIS were further developed to enable the assessment of patients with multiple injuries. These systems include for example the Injury Severity Score (ISS) (Baker et al., 1974), the New Injury Severity Score (NISS) (Osler et al., 1997) and the Trauma and Injury Severity Score (TRISS) (Champion et al., 1983). Table 1. presents the differences and features of these scoring systems.

Table 1. Characteristics of the Abbreviated Injury Scale (AIS) based trauma scoring systems (Own illustration, generated partly by ChatGPT, ChatGPT, July 15, 2025, OpenAI).

Scoring system	Purpose	Inputs	Strenghts	Limitations
AIS	Classification of the severity of individual injuries	Anatomical injury score (scale 1–6)	Serves as the foundation for other scoring systems; precise for individual injuries	Does not account for multiple injuries or physiological response
ISS	Summarizes the severity of injuries in three different body regions	AIS scores from the three most severely injured body regions	Useful overall score across distinct body areas	Underestimates severity if multiple serious injuries are located in one region
NISS	Improved version of ISS that includes the three most severe injuries regardless of region	AIS scores of the three most severe injuries	Better sensitivity for multiple injuries in the same area	May overestimate severity when injuries cluster in one region
TRISS	Predicts survival by combining anatomical and physiological data	ISS + Glasgow Coma Scale + Systolic BP + Respiratory rate + Age	Accurate in estimating mortality; integrates trauma severity with patient condition	Complex to use; relies on rapid and accurate physiological measurements

The ISS calculates the sum of the squares of the highest AIS scores from three different body regions to determine the prognosis of trauma patients. However, the patients´s age or the specific injury combinations are not observed. NISS on the other hand considers the highest AIS scores from the three most severe injuries regardless of body region, providing a more precise overall injury assessment. In TRISS, the patients´s age and physiological data are combined with the ISS to better predict individual patients´s injury outcome. However, a limitation of the TRISS system is that in intubated patients, the GCS cannot be reliably assessed.

The RISC II (Revised Injury Severity Classification, version 2) predictive model, developed based on the TraumaRegister DGU™ dataset, is used to assess the risk of death in severely injured patients. The model includes variables describing the patients´s physiological condition (e.g. blood pressure, oxygen saturation, pupillary response and haemoglobin), injury severity (AIS severity level; worst and second worst injury), patient background (age, sex, comorbities) and treatment-related factors (e.g. cardiopulmonary resuscitation) (Lefering et al., 2014).

The AIS based systems have been criticized for their limited usability due to the complexity of coding requiring expert training. To enhance the prognostic value and to facilitate the broader use of the system, both in clinical practice and for research purposes, the ICD-based Injury Severity Score (ICISS) was introduced (Osler et al.,

1996). In addition to being more accessible for hospital use, the system is ideal for research and epidemiological studies, because of the use of ICD codes. The challenges of the system on the other hand lie heavily in depending on the quality of patients data and not including physiological variables. ICISS is well-suited for population-level analysis, but is a weak tool for clinical assessment in acute situations.

2.2.2 Traumatic brain injury

TBI is defined as an alteration in brain function (i.e, a decreased or a loss of consciousness, any period of retrograde or post-traumatic amnesia, neurologic deficit such as weakness, loss of balance, change in vision, aphasia etc., or any alteration in mental state at the time of the injury), or other evidence of brain pathology (i.e, visual, neuroradiologic or laboratory confirmation of brain damage), caused by external force (Menon et al., 2010).

The severity of TBI is categorized based on clinical evaluation and standard imaging (computed tomography CT or magnetic resonance imaging MRI) as mild, moderate or severe. The Glasgow coma scale (GCS) is used to assess the level of consciousness based on eye opening, speech and movement response (Table 2). GCS of 13–15 defines mild TBI, GCS 9–12 moderate TBI and GCS 3-8 a severe TBI. A mortality rate as high as 30–40% is associated with severe TBI (Rosenfeld et al., 2012). However, substantial physical, emotional and cognitive disabilities can occur frequently after mild and moderate TBIs also (Maas et al., 2017).

Table 2. Glasgow coma scale scoring (Own illustration).

Eye opening	Score	Verbal response	Score	Motor response	Score
Spontaneous	4	Oriented	5	Obeys commands	6
To speech	3	Confused	4	Localizes pain	5
To pain	2	Inappropriate words	3	Withdraws from pain	4
None	1	Incomprehensible sounds	2	Flexion to pain	3
		No response	1	Extension to pain	2
				No response	1

Internationally TBI affects more than 50 million people each year with enormous economic consequences and remains the leading cause of mortality in young adults (Maas et al., 2017). The incidence of TBI is increasing globally. In low- and middle-income countries RTAs and violence-related injuries are the leading cause of TBIs, whereas in developed countries falls dominate as the leading cause of TBI and the median age of TBI patients is on the rise (Maas et al., 2008; Peeters et al., 2015; Roozenbeek et al., 2013).

According to previous literature, TBIs are frequent in facial fracture patients. Some 5 to 67 % of facial fracture patients sustain a concomitant TBI. (Alvi et al., 2003; Arslan et al., 2014; Carlin et al., 1998; Lim et al., 1993; McCarty et al., 2020; Pappachan and Alexander, 2006; Rajandram et al., 2014) This wide range of occurrence for concomitant TBI is mainly due to the discrepancy in the definition of TBI.

2.2.2.1 Anatomical distribution

TBI can present as a focal injury, confined to a specific area of the brain or as a diffuse injury affecting a more widespread area. The membranous structures protecting the brain, presented in Figure 2 (i.e, outermost dura mater, arachnoid mater in the middle and innermost pia mater) determine the location of the hematoma forming around the brain resulting from the injury.

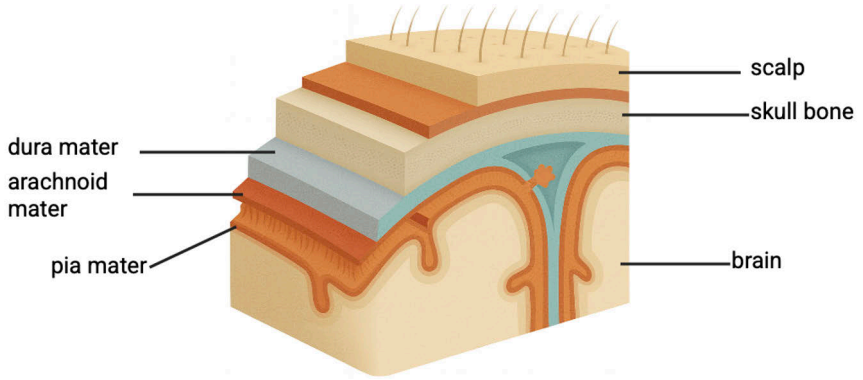

Figure 2. The membranous structures surrounding the brain (Own drawing, generated partly by ChatGPT, ChatGPT, July 15, 2025, OpenAI and partly by BioRender.com).

Bleeding between the skull and the dura mater results in epidural hematoma, whereas bleeding between the dura and the arachnoid mater causes a subdural hematoma. Thus epidural and subdural hematomas cause pressure on the outside of the brain. Bleeding between the arachnoid mater and the pia mater results as a subarachnoid hemorrhage, causing blood to leak into the cerebrospinal fluid. Intracerebral hematoma results from bleeding into the brain tissue. Figure 3 illustrates the anatomical location of the hematoma. Diffuse axonal injury (DAI) is caused by stretching or twisting of nerve fibers due to the effect of a strong acceleration-deceleration movement. DAI causes a widespread damage to the white matter tracts of the brain particularly at the junction of the grey and white matter and deep white matter such as corpus callosum.

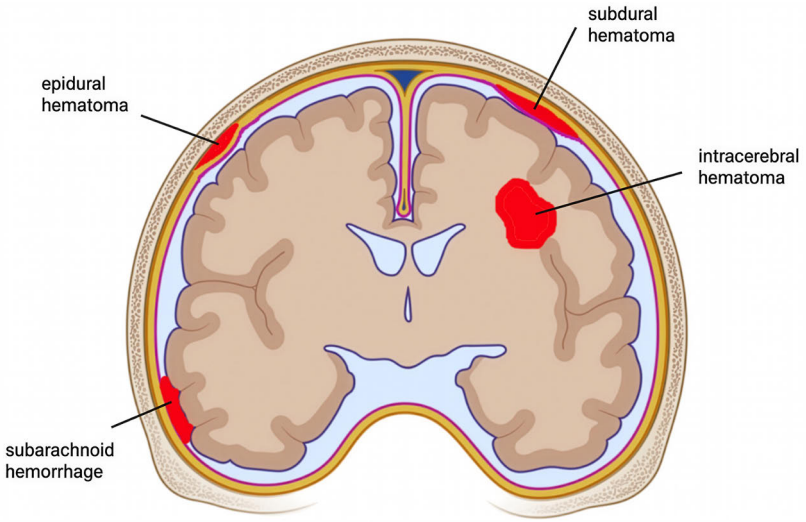

Figure 3. Location of epidural and subdural hematoma, subarachnoid hemorrhage and intracerebral hematoma (Own drawing, generated partly by ChatGPT, ChatGPT, July 15, 2025, OpenAI and partly by BioRender.com).

2.2.2.2 Pathophysiology

The pattern and extent of damage of TBI varies greatly and is determined by the intensity, direction and type of the external force causing the injury. TBI progresses through two distinct phases: the immediate primary injury and the evolving secondary injury. While the primary injury results directly from mechanical forces causing physical damage to brain structures, the secondary injury evolves gradually with time and is driven with a complex cascade of cellular and molecular responses involving mitochondrial function, neurotrasmitter release and disruptions in ion balance. These disturbances can lead to cell death, brain swelling and increased intracranial pressure (ICP). Systemic factors such as fever, electrolytic imbalances, coagulation disorders, low oxygen levels or hypotension can further worsen the condition. (Kochanek et al., 2015; Pearn et al., 2017).

The primary injury caused by mechanical force cannot be modified by treatment but only by preventive measures, such as improved traffic safety, whereas the secondary injury can be influenced by therapeutic means. To avoid secondary complications of TBI, early onset of treatment is crucial. A diagnostic delay of TBI may lead to deterioration of neurological status, increased morbidity, prolonged hospitalization and poorer functional outcomes. Adequate oxygenation, ventilation and brain perfusion need to be maintained and increased ICP monitored and if necessary, treated medically or surgically. In addition, treatment of fever and seizures, as well as correction of anemia, electrolyte imbalances, and coagulation disorders, is necessary (Ng and Lee, 2019; Vos and Diaz-Arrastia, 2015; Wagner et al., 2021).

2.2.3 Blunt cerebrovascular injury

BCVI is a quite uncommon but potentially fatal injury, resulting from blunt force injuries to the common carotid arteries, internal carotid arteries (ICA) and/or vertebral arteries (VA) illustrated in Figure 4. Injury mechanisms stretching or twisting the artery against the bony structures can cause BCVI. Also compressive forces by bony fragments resulting from a direct blow to the neck can cause BCVI. Typically BCVIs are caused by high energy mechanisms such as MVAs or falls from height, hyperextending or rotating the neck. Some lower energy injuries, such as chiropractic manipulation, strangulation or sport injuries can also injure the arteries (Brommeland et al., 2018; Rutman et al., 2018). The symptoms often appear with a delay, making the diagnosis challenging. The risk of lethal complication, such as post-injury cerebral infarction is significant if left untreated (McKevitt et al., 2002; Schneidereit et al.,2006). The primary and usually sufficient treatment is anti-thrombotic medication (Russo et al., 2021).

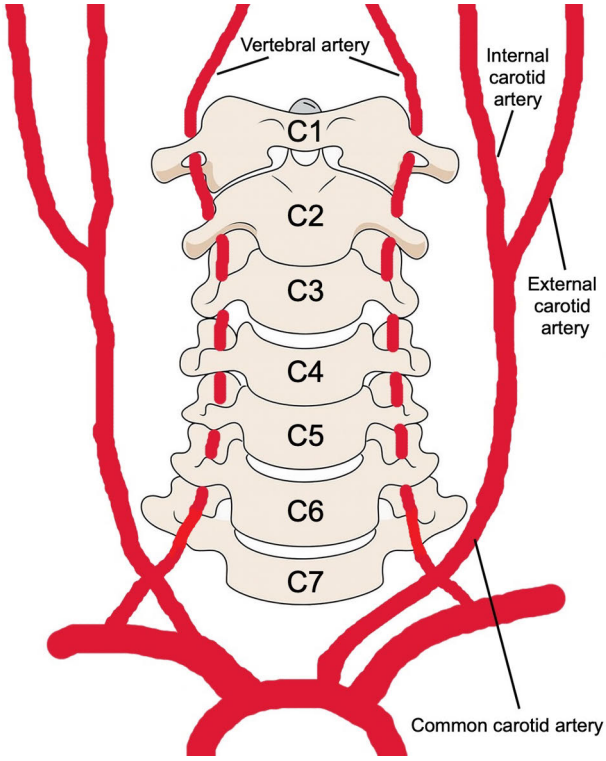

Figure 4. Cervical vessels (Own drawing, generated partly by ChatGPT, ChatGPT, July 16, 2025, OpenAI).

Severe head injuries are significantly associated with the risk of BCVI (Esnault et al., 2017; Weber et al., 2018). According to the literature, also cervical spine, thoracic and high energy injuries have been found to be significantly associated with BCVIs. Among these, the occurrence of BCVIs has been reported to be 1-14% (Cothren et al., 2009; Esnault et al., 2017; Mundinger et al., 2013; Varjonen et al., 2018; Weber et al., 2018). Since craniofacial fracture patients are often prone to hyperextension of the neck and sudden head rotations, they are a special group among trauma patients when estimating the possibility of BCVI. A correlation between craniofacial fractures and BCVI has been reported in the literature and almost one fifth of the patients with different types of craniofacial fractures have been reported to sustain BCVIs. (Mundinger et al., 2013; Varjonen et al., 2018).

2.2.3.1 Pathophysiology and grading

The pathofysiology of BCVIs still remains partly unclear. The stretching, twisting or shearing injury causes a dissection of the arterial intima, resulting in platelet accumulation and blood clot formation at the site of the injury. Alternatively, an intramural hematoma (IMH) can be formed in the artery wall. Following the injury, a clot can obstruct the arterial lumen or move cranially (embolus) potentially causing a stroke. The arterial wall might also be severely weakened by the damage, resulting in pseudoaneurysm or complete rupture of the artery (Rutman et al., 2018)

The severity of BCVI ranges widely. A commonly accepted scale to grade BCVI lesions is the Denver Scale, which divides the lesions into five categories according to severity. In a Grade I lesion, vessel wall irregularity, dissection or IMH causes a less than 25% stenosis. Grade II is defined as dissection or IMH with over 25% luminal stenosis, but without complete occlusion of the vessel. A raised intimal flap or intraluminal thrombus may appear in a Grade II lesion. A traumatic pseudoaneurysm is categorized as a Grade III lesion. In a Grade IV injury, a complete vascular occlusion exists. A Grade V injury causes a complete vessel transection and extravasation (Biffl et al., 1999a; Rutman et al., 2018). In their meta-analysis, Tran et al. demonstrated an increased stroke risk by as much as two to three-fold for Grade III or IV injuries, as compared to Grade I and II injuries (Tran et al., 2024).

2.2.3.2 Screening and diagnosis

The clinical diagnosis of BCVIs is challenging. According to prior research, a vast majority, up to 66-90% of patients with BCVI are asymptomatic when arriving to hospital (Burlew et al., 2012; Geddes et al., 2016). In addition, symptoms typically present with a delay, hours or even days after the injury (Cothren et al., 2004).

Early diagnosis and treatment decreases the stroke and mortality rates (Cothren et al., 2004; Fabian et al., 1996). To facilitate rapid diagnosis and to enable treatment before the patient becomes symptomatic, various clinical screening guidelines for BCVI have been developed. Before the use of screening protocols, the rates of stroke were reported at 80% and BCVI associated mortality was reported to be 40% (Davis et al., 1990). The recent literature reports a risk of stroke at 7-27% and risk of mortality at 9-30% after an untreated BCVI (Bensch et al., 2019a; Biffl et al., 2009; Brommeland et al., 2018; Callcut et al., 2012; Cothren et al., 2004, 2009; Esnault et al., 2017; McNutt et al., 2018; Miller et al., 2002; Russo et al., 2021; Weber et al., 2018).

The primary diagnostic method for BCVI after clinical evaluation is CT angiography (CTA).The enhanced Denver guidelines, initially presented in 1999 (Biffl et al., 1999b) and updated in 2012 (Burlew et al., 2012), is the most commonly clinically used screening criteria for BCVI. The criteria involve signs/symptoms and risk factors for BCVI, to determine whether the trauma patient should be imaged with CTA of the neck to detect possible BCVI. Table 3 presents the enhanced Denver screening criteria for BCVI.

Table 3. The enhanced Denver screening guidelines for BCVI according to Burlew et al. (Burlew et al.,2012) (Own illustration).

Signs/Symptoms of BCVI
• Stroke on CT or MRI • Focal neurologic defect • A new neurologic deficit inconsistent with head CT • Expanding cervical hematoma or cervival bruit in patients <50 years old • Arterial hemorrhage from mouth/nose/neck
Risk factors for BCVI

• High energy trauma mechanism, hanging injury or hard blunt cervival hit associated with:
  • Severe thoracic injury including blunt cardiac rupture, thoracic vascular injuries and upper rib fractures
  • Severe traumatic brain injury with GCS <6 or diffuse axonal injury
  • Skull, basilar skull or occipital condyle fracture
  • Le Fort II or III displaced midface or mandibular fracture
  • Cervival spine fracture, subluxation or ligamentous injury
  • Scalp degloving
  • Seat-belt-sign with significant swelling, pain or altered mental status

3 Aims

This dissertation aimed to report the occurrences and types of associated injuries (AIs) in patients with facial fractures. The purpose was to identify factors worsening the prognosis and increasing morbidity and mortality in facial fracture patients with AIs.

The specific aims were as follows:

1. To identify frequencies of and risk factors for different types of AIs, and to compare these between adults and elderly patients (Study I).
2. To determine the occurrence and risk factors for BCVIs (Study II).
3. To clarify the occurrence and risk factors for TBI (Study III).
4. To investigate the occurrence of and risk factors for missed TBI diagnosis (mTBId) at primary evaluation , and to compare these between adults and elderly patients (Study IV).

4 Materials and Methods

4.1 Study design

This dissertation study, focusing on AIs in facial fracture patients in the Helsinki and Uusimaa regions, is a retrospective cohort study consisting of four sub-studies. Studies I, III and IV had a six-year study period from January 2013 to December 2018. Study II had a three-year study period, from January 2016 to December 2018.

4.2 Study populations

Included were all adult facial fracture patients diagnosed and treated at a tertiary trauma hospital (Töölö Hospital, Helsinki University Hospital, Helsinki Finland) providing care to approximately 1.6 million inhabitants. Altogether 2682 adult facial fracture patients between 2013 and 2018 and 115 patients with cranial fractures between 2016 and 2018 were identified for the study.

Study I included all 2682 facial fracture patients at least 18 years of age at the time of the injury who were diagnosed and treated during the years 2013–2018.

Study II consisted of craniofacial fracture patients who had been screened for BCVIs with CTA during 2016-2018. Of the total of 1912 craniofacial fracture patients, 1155 patients were excluded due to not being screened with CTA and four patients were excluded due to sustaining firearm or stabbing injuries. The final sample size remained 753 patients.

Study III included all adult patients with mandibular and/or midfacial fractures, who had undergone imaging (computed tomography (CT) or magnetic resonance imaging (MRI)) of the brain in connection with facial fracture diagnosis between 2013-2018. Of the total of 2682 facial fracture patients, 846 were excluded from the analyses: 765 patients had not undergone imaging of the brain and 81 patients had exclusively upper facial third fractures. In total, the sample size was 1836.

Study IV included all adult facial fracture patients with a primary Glasgow Coma Scale (GCS) score of 13 or more and associated TBI. Of the 2682 facial fracture patients, 2277 patients were excluded due to lack of associated TBI and 152 patients due to a primary GCS lower than 13, leaving 253 patients in the final analyses.

4.3 Outcome variables

The primary outcome variable in Study I was AI. Additional outcome variables were affected organ systems, number of affected organ systems, need for intensive care and mortality during hospitalization. In Study II the main outcome variable was BCVI. In Study III, the outcome variable was TBI. In Study IV the outcome variable was mTBId, which was defined as being present when the possibility of a TBI was not considered at the primary evaluation but was later diagnosed.

4.4 Predictor variables

The primary predictor variable in Studies I and IV was age, i.e. adults vs elderly. The group of elderly consisted of patients at least 60 years at the time of the injury in Study I, and patients at least 65 years at the time of the injury in Study IV. In Study II, the primary predictor variable was the type of craniofacial fracture, classified as cranial fracture, combined craniofacial fracture and facial fracture. The primary predictor variable in Study III was the type of AI grouped as AI outside the head and neck (injuries of the upper- and lower extremities, chest, pelvis, spine (excluding cervical spine) and abdomen), associated cranial fracture (fractures of the skull, skull base and/or the upper facial third) and associated neck injury (cervical spine injury, BCVI and/or laryngeal injury).

Secondary predictor variables in Study II were cervical injury, intracranial hemorrhage, GCS score less than 6, thoracic injury and high-energy trauma. Additional predictor variable in Study II was the specific type of craniofacial fracture subtype. Isolated cranial fractures were grouped as fracture of the base of the skull, other part of the skull, combined skull fracture and fracture extending to skull foramina (carotid canal, foramen magnum or carotid canal with foramen magnum). Isolated facial fractures were grouped as follows: 1) zygomatic-maxillary-orbital complex, 2) mandible, 3) combined midfacial, 4) combination of facial thirds, 5) nasal, 6) upper third and 7) other.

4.5 Explanatory variables

The explanatory variables included in the analyses were sex (Studies I-IV), age (Studies II and III), mechanism of trauma (Studies I, II and IV), type of facial fracture (Studies I, III and IV), involvement of alcohol in the injury (Studies I, II and IV), energy of injury (Studies III and IV) and medication predisposing to bleeding (Studies III and IV). In addition, AI outside the head and face and number of affected organ systems were included as explanatory variables in Study IV.

Mechanism of trauma was categorized as assault, fall on ground level, fall from height, fall from stairs, bicycle accident, motor vehicle accident (MVA) and

other/unknown in Studies I and II. Additionally, in Study I the mechanism struck by object was reported. In Study IV mechanisms of trauma were categorized as assault, fall from height or stairs, fall on ground level, traffic and other/unknown. In Studies I and IV type of facial fracture was classified according to facial thirds as follows: 1) exclusively mandibular fracture, 2) exclusively midfacial fracture, 3) exclusively upper facial third fracture (orbital roof and/or the frontal sinus) or 4) combined fracture (i.e. combination of fractures of different facial thirds). In Study III type of facial fracture was classified as exclusively mandibular, exclusively midfacial or combined fracture (i.e. mandibular and midfacial fracture). Involvement of alcohol was verified from the patient charts (blood sample, use of a breathalyzer or history given by the patient or paramedics) and classified as "no alcohol" if the anamnesis could not be confirmed. Industrial injuries, RTAs and falls from over three meters were categorized as high energy injuries (Evans et al., 2010).

4.6 Statistics

Descriptive statistics using counts and percentages were used to summarize patient characteristics and injury patterns. The Pearson $\chi 2$ test or Fisher´s exact test (if expected values were less than five) were used to analyze the categorical variables. The Wilcoxon test was used to analyze continuous variables.

In studies I, III and IV risk ratios (RR) with 95% confidence intervals (CIs) were calculated to examine the risk of the described outcomes. To estimate the associations between the outcomes and the independent variables, logistic regression analysis was conducted. Unadjusted and adjusted odds ratios (ORs) with 95% CIs were calculated. Multivariable logistic regression analysis was done in Studies I, II and III.

In all the studies (I-IV) p-values <0.05 were considered statistically significant. Statistical analyses were conducted using SPSS software (IBM SPSS v27.0, IBM Corp., Armonk, NY) in Study I, Stata Version 11 (Stata Corp LP, College Station, TX, USA in Study II, SAS version 9.4 (SAS Institute Inc. Cary, NC, USA) in Study III and JMP version 17 (JMP Pro v17, Cary, NC,USA) in Study IV.

4.7 Ethical considerations

This study was conducted as a retrospective registry analysis. In accordance with Finnish legislation, individual patient consent was not required for this type of register-based research. The registry data were obtained through a review of patients´medical records. The Helsinki declaration guidelines were followed throughout all of the sub-studies. The Internal Review Board of the Head and Neck Center of the Helsinki University Hospital, Helsinki, Finland, approved all the sub-studies of this dissertation.

5 Results

5.1 Study I

Of the total 2682 patients with facial fractures, AIs were sustained by 854 (31.8%), the brain being the most commonly affected organ system. TBI was observed in 405 (15.1%) of the 2682 facial fracture patients. The anatomical distribution of AIs is presented in detail in Figure 5.

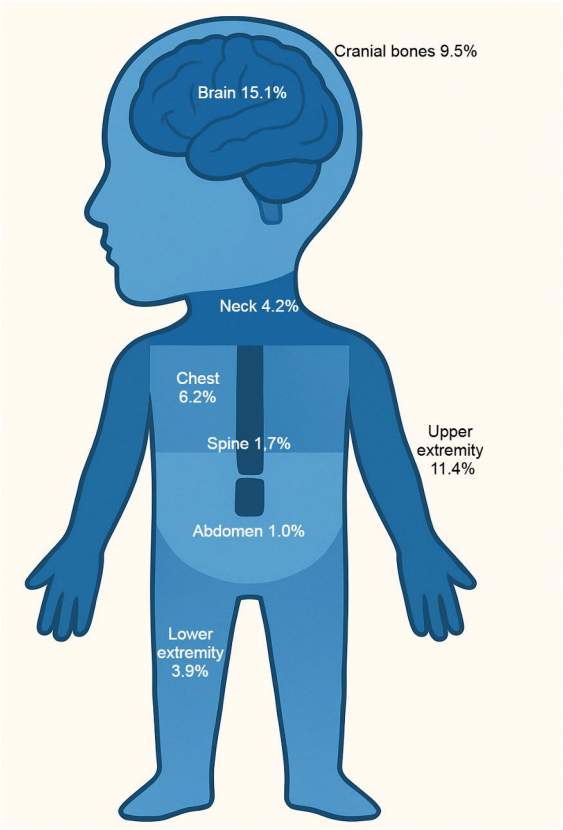

Figure 5. The anatomical distribution of associated injuries (AIs) in facial fracture patients (Own drawing, generated partly by ChatGPT, ChatGPT, July 17, 2025).

Table 4 summarizes the descriptive statistics of the 854 patients with AIs. The vast majority of the patients with AIs were male (69.6%). The mean age of the facial

fracture patients with AIs was 53.5 years (range 18 to 98 years). Fall at ground level (28.2%), motor vehicle accident (MVA) (15.1%) and assault (14.8%) were the leading causes of AIs among patients with facial fractures. AIs were most commonly sustained by patients with exclusively midfacial fractures (61.1%). TBI was identified in approximately half (47.4%) of the facial fracture patients with AIs. Upper extremity injuries and cranial bone fractures were also frequently observed, occurring in 35.9% and 30.0% of facial fracture patients with AIs, respectively. Two

Table 4. The descriptive statistics of the 854 facial fracture patients with Ais.

Variable	Number of patients	%
Sex		
Male	594	69.6
Female	260	30.4
Age (years)		
Mean	53.5	
Range	18.0-98.0	
Elderly (≥60)	330	38.6
Adults (<60)	524	61.4
Mechanism of trauma		
Fall at ground level	241	28.2
Motor vehicle accident	129	15.1
Assault	126	14.8
Bicycle	124	14.5
Fall from height	120	14.1
Fall from stairs	58	6.8
Struck by object	29	3.4
Other/Unknown	27	3.2
Intoxication		
Yes	304	35.6
Type of facial fracture		
Exclusively midfacial	522	61.1
Combined	161	18.9
Exclusively mandibular	111	13.0
Exclusively upper third	60	7.0
Affected organ systems		
Brain	405	47.4
Upper extremity	307	35.9
Cranial bone	256	30.0
Chest	165	19.3
Neck*	112	13.1
Lower extremity	104	12.2
Spine**	46	5.4
Abdomen	28	3.3
No of affected organ systems		
1	514	60.2
≥ 2	340	39.8
Intensive care		
Yes	243	28.5
In Hospital Mortallity	31	3.6

*Including cervical spine, blunt cerebrovascular and laryngeal injuries
**Excluding cervical spine injuries

or more organ systems were affected in 39.8% of facial fracture patients with AIs. Over one third (35.6%) of the patients with AIs were intoxicated at the time of the injury. Almost one third (28.5%) of the patients were treated at the ICU. In hospital mortality rate was 3.6% for the patients with AIs.

The distribution of controlled variables by age groups is summarized in Table 5. The elderly group (at least 60 years of age) consisted of 751 patients, representing 28% of the total study population. The proportion of female patients was significantly higher in the elderly patient group (50.6%) when compared to younger adults (19.5%). Mechanism of trauma and types of facial fractures also significantly differed between age groups. Among the elderly patients, fall at ground level was by far the most common mechanism of injury (63.8%), whereas assault was the most common mechanism of injury in younger adults (40.3%). Intoxication at the time of

Table 5. The distribution of age, sex, mechanism of trauma and type of facial fracture in 751 elderly and 1931 adult patients with facial fractures (Modified from Study I).

Variable	Elderly patients Number of patients (% of 751)	% of n	Adult patients Number of patients (% of 1931)	% of n	P-value*
All patients (n=2682)	751	28.0	1931	72.0	
Age					
Mean	74.5		36.8		
Range (yrs)	60.1–102.5		18.0–59.9		
Sex					<.001
Male (n=1926)	371 (49.4)	19.3	1555 (80.5)	80.7	
Female (n=756)	380 (50.6)	50.3	376 (19.5)	49.7	
Mechanism of trauma					<.001
Fall at ground level (n=805)	479 (63.8)	59.5	326 (16.9)	40.5	
Bicycle (n=326)	68 (9.1)	20.9	258 (13.4)	79.1	
Fall from stairs (n=115)	58 (7.7)	50.4	57 (3.0)	49.6	
Motor vehicle accident (n=182)	48 (6.4)	26.4	134 (6.9)	73.6	
Fall from height (n=155)	30 (4.0)	19.4	125 (6.5)	80.6	
Assault (n=806)	27 (3.6)	3.3	779 (40.3)	96.7	
Struck by object (n=216)	17 (2.3)	7.9	199 (10.3)	92.1	
Other/Unknown (n=77)	24 (3.2)	31.1	53 (2.7)	68.9	
Type of facial fracture					<.001
Exclusively midfacial (n=1566)	511 (68.0)	32.6	1055 (54.6)	67.4	
Exclusively mandibular (n=754)	133 (17.7)	17.6	621 (32.2)	82.4	
Combined (n=278)	85 (11.3)	30.6	193 (10.0)	69.4	
Exclusively upper third (n=84)	22 (3.0)	26.2	62 (3.2)	73.8	
Intoxication					
Yes (n=986)	154 (20.5)	15.6	832 (43.1)	84.4	<.001

*χ^2 test

the trauma was significantly more common in younger adults. The frequency of intoxication was 43.1% in younger adults, although 20.5% of the elderly were also intoxicated at the time of the injury, which is noteworthy.

Table 6. presents the results of the multivariable logistic regression analysis for AIs. Overall, increased age, mechanism of trauma and type of facial fracture were significant predictors for AIs in patients with facial fractures. As compared to younger adults, the elderly had 1.9-fold odds for AIs. Patients with exclusively midfacial fractures had 2.3-fold, patients with combined fractures had 5.6-fold and patients with exclusively upper third fractures had 12.5-fold odds for AIs, when compared to patients with exclusively mandibular fractures. Patients involved in high energy injuries, such as MVAs and falls from height had the greatest odds for AIs.

Table 6. Multivariable logistic regression analysis for associated injury (AI) (Modified from Study I).

Variable	OR(95% CI)	P-value
Age group		
Elderly	1.9 (1.5–2.5)	<.001
Adults	ref	
Sex		
Female	ref	
Male	1.1 (0.9–1.3)	NS
Mechanism of trauma		
Fall at ground level	2.1 (1.4–3.4)	.001
Bicycle	3.8 (2.4–6.1)	<.001
Fall from stairs	4.5 (2.6–8.0)	<.001
Motor vehicle accident	13.7 (8.1–23.1)	<.001
Fall from height	19.2 (10.9–33.6)	<.001
Assault	1.3 (0.9–2.1)	NS
Struck by object	ref	
Other/Unknown	2.7 (1.4–5.1)	.003
Type of facial fracture		
Exclusively midfacial	2.3 (1.8–3.0)	<.001
Exclusively mandibular	ref	
Combined	5.6 (4.0–7.9)	<.001
Exclusively upper third	12.5 (7.2–21.8)	<.001

Abbreviations: OR, odds ratio; CI, confidence interval; ref, reference

Table 7 presents the results of the adjusted logistic regression analysis by secondary outcomes between age groups. After adjusting for mechanism of trauma

and type of facial fracture, the elderly were 1.8 times more likely to suffer injuries involving multiple organ systems and showed higher incidence of brain and neck injuries, with adjusted odds ratios of 2.2 and 2.3, respectively. In addition, in-hospital mortality was substantially elevated among the elderly, with a 6.8-fold odds compared to younger adults.

Table 7. Logistic regression analysis by secondary outcomes between age groups (Modified from Study I)

Secondary Outcome	Adults OR* (95% CI)	Elderly OR* (95% CI)	P-value
Affected organ systems ≥ 2	ref	1.8 (1.3–2.5)	<.001
Brain	ref	2.2 (1.6–2.9)	<.001
Upper Extremity	ref	1.3 (0.6–1.7)	NS
Chest	ref	1.1 (1.0–2.2)	NS
Cranial bone	ref	1.4 (1.0–2-0)	NS
Neck	ref	2.3 (1.5–3.6)	<.001
Lower extremity	1.6 (0.9–2.7)	ref	NS
Spine	ref	1.3 (0.6–2.6)	NS
Abdomen	1.4 (0.5–3.8)	ref	NS
Intensive care	ref	1.3 (0.9–1.8)	NS
In hospital mortality	ref	6.8 (2.9–15.6)	<.001

Abbreviations: OR, odds ratio; CI, confidence interval; ref, reference.
*Adjusted with mechanism of trauma and type of facial fracture

5.2 Study II

Out of 1912 patients with craniomaxillofacial fractures, 753 were screened for BCVIs using CTA. Among those screened, BCVIs were confirmed in a small but clinically significant subgroup of 33 (4.4%) patients. BCVI occurrence differed based on fracture type, presenting in 8.7% of patients with cranial fractures, 7.1% of patients with combined craniofacial fractures and 3.1% of patients with facial fractures (Table 8).

The distribution of explanatory variables by BCVI occurrence is summarized in Table 8. Isolated cranial fractures were more frequently observed in patients with BCVI compared to those without BCVI. BCVI occurrence was significantly associated with the fracture extending to the carotid canal and the foramen magnum. High energy trauma correlated significantly with BCVI occurrence. BCVI presence was strongly associated with both the anatomical location of the fracture and the mechanism of trauma.

Table 8. Distribution of controlled variables by occurrence of blunt cerebrovascular injuries (BCVI) (Modified from Study II)

Variable	Patients with BCVI Number of patients (% of 33)	% of n	Patients without BCVI Number of patients (% of 720)	% of n	P-value*
All (n=753)	33	4.4	720	95.6	
Sex					NS
Male (n=549)	26 (78.8)	4.7	523 (72.6)	95.3	
Female (n=204)	7 (21.2)	3.4	197 (27.4)	96.6	
Age (years)					NS
Median	34.7		45.7		
IQR	25.4–58.6		30.9–63.6		
Mechanism of trauma					
Fall at ground level (n=208)	7 (21.2)	3.4	201 (27.9)	96.6	NS
Assault (n=20)	4 (12.1)	2.4	162 (22.5)	97.6	NS
Motor vehicle accident (n=115)	12 (36.4)	10.4	103 (14.3)	89.6	.001
Bicycle (n=88)	3 (9.1)	3.4	85 (11.8)	96.6	NS
Fall from height (n=66)	4 (12.1)	6.1	62 (8.6)	93.9	NS
Fall from stairs (n=43)	1 (3.0)	2.3	42 (5.8)	97.7	NS
Other/Unknown (n=67)	2 (6.1)	3.0	65 (9.0)	97.0	NS
Type of craniofacial fracture					
Isolated cranial (n=115)	10 (30.3)	8.7	105 (14.6)	91.3	.014
Combined (n=85)	6 (18.2)	7.1	79(11.0)	92.9	NS
Isolated facial (553)	17 (51.5)	3.1	536 (74.4)	96.9	.004
Energy of injury					.001
High (n=181)	16 (48.5)	8.8	165 (22.9)	91.2	
Associated injuries					<.001
Cervical injury (n=49)	5 (15.2)	10.2	44 (6.1)	89.8	NS
Intracranial hemorrhage (n=236)	17 (51.5)	7.2	219 (30.4)	92.8	.011
GCS score <6 (n=51)	6 (18.2)	11.8	45 (6.3)	88.2	.019
Thoracic Injury (n=85)	11 (33.3)	12.9	74 (10.3)	87.1	<.001
Fracture extending to skull foramina					
No (n=718)	27 (81.8)	3.8	691 (96.0)	96.0	
Yes (n=35)	6 (18.2)	17.1	29 (4.0)	82.9	
Carotid canal (n=23)	4 (12.1)	17.4	19 (2.6)	82.6	NS
Foramen magnum (n=8)	0 (0.0)	0.0	8 (1.1)	100.0	NS
Carotid canal with foramen magnum (n=4)	2 (6.1)	50.0	2 (0.3)	50.0	.040
Number of associated injuries					<.001
0 (n=459)	12(36.4)	2.7	438 (60.8)	97.3	
1 (n=209)	9(27.3)	4.3	200 (27.8)	95.7	
2 (n=73)	7(21.2)	9.6	66 (9.2)	90.4	
3 (n=18)	4(12.1)	22.2	14 (1.9)	77.8	
4 (n=3)	1(3.0)	33.3	2 (0.3)	66.7	
Alcohol involved					
Yes (n=281)	8(24.2)	2.8	273 (37.9)	97.2	NS

Abbreviations: IQR, interquartile range; GCS, Glagow coma scale, *χ^2 test and Fishers´s exact test

The results of the univariate logistic regression analysis are presented in Table 9. The odds for BCVI was significantly increased in patients with isolated cranial fractures, patients involved in high-energy injuries, and particularly patients involved in MVAs. In addition, the number of AIs correlated significantly with the odds for BCVI, with each additional injury leading to a greater odds for BCVI. Thoracic injury increased the odds for BCVI over four times. Cervical injury, intracranial hemorrhage and a GCS score less than 6 increased the odds for BCVI more than two-fold, with odds ratios of 2.7, 2.4 and 2.3. In the multivariate logistic regression analysis, presented in Table 10, only thoracic injuries significantly increased the odds for BCVI.

Table 9. Univariate logistic regression analysis for blunt cerebrovascular injuries (BCVI) (modified from Study II).

Variable	OR(95% CI)	P-value
Sex		
Female	0.7 (0.3–1.7)	NS
Age	1.0 (1.0–1.0)	NS
Mechanism of trauma		
Fall at ground level	0.7 (0.3–1.6)	NS
Assault	0.5 (0.2–1.4)	NS
Motor vehicle accident	3.4 (1.6–7.2)	.001
Bicycle	0.8 (0.2–2.5)	NS
Fall from height	1.5 (0.5–4.3)	NS
Fall from stairs	0.5 (0.1–3.8)	NS
Other/Unknown	0.7 (0.2–2.8)	NS
Type of craniofacial fracture		
Isolated cranial	2.6 (1.2–5.5)	.017
Combined	1.8 (0.7–4.5)	NS
Isolated facial	0.4(0.2–0.7)	.005
Energy of injury		
High	3.2 (1.6–6.4)	.001
Associated injuries		
Cervical injury	2.7 (1.0–7.5)	.048
Intracranial hemorrhage	2.4 (1.2–4.9)	.013
GCS score <6	2.3 (1.3–8.5)	.012
Thoracic injury	4.3 (2.0–9.4)	<.001
Number of associated injury		
0	ref	
1	1.6 (0.7–4.0)	NS
2	3.9 (1.5–10.2)	.006
3	10.4 (3.0–36.4)	<.001
4	18.3 (1.6–215.3)	.021
Alcohol involved		
Yes		NS

Abbreviations: OR, odds ratio; CI, confidence interval; GCS, Glasgow coma

Table 10. Multivariable logistic regression analysis for blunt cerebrovascular injury (Modified from Study II).

Variable	OR(95% CI)	P-value
Type of craniofacial fracture		
Isolated cranial	2.3 (1.0–5.3)	NS
Combined	1.8 (0.7–4.8)	NS
Isolated facial	ref	
Age	1.0 (1.0–1.0)	NS
Motor vehicle accident	2.1 (0.9–4.7)	NS
Cervical injury	2.0 (0.7–5.6)	NS
Thoracic injury	2.6 (1.1–6.0)	.023

Abbreviations: OR, odds ratio; CI, confidence interval

In total, the 33 patients sustained 39 BCVIs. Six of the patients suffered multiple BCVIs. After retrospectively evaluating the patients with BCVI, it was found that 30 (90,9%) of the patients met the enhanced Denver screening criteria. The three patients not fulfilling the criteria, suffered midface and upper face fractures. Majority of the BCVIs were located in the internal carotid arteries or common carotid artery (69.2%) and categorized as grade 2 injuries (53.8%). Most of the BCVIs were located at the upper cervical spine levels C0-C2 (74.4%). Figure 6. illustrates the anatomical distribution of the 39 identified BCVI lesions.

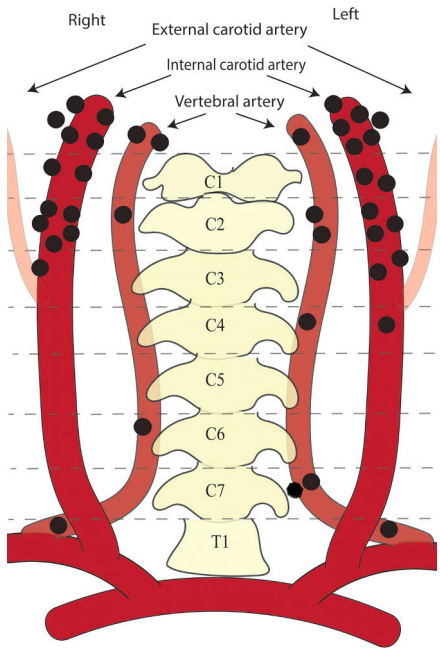

Figure 6. The anatomical distribution of the 39 identified BCVI lesions (Modified from Study II).

5.3 Study III

Out of 1836 patients with mandibular or/and midfacial fractures, 365 (19.9%) sustained a concomitant TBI. Overall, AIs were detected in 641 (34.9%) patients. Cranial fractures presented in 278 (15.1%), neck injuries in 104 (5.7%), and AIs outside the head and neck in 295 (16.1%) of the patients. The descriptive statistics of the study cohort are presented in Table 11.

Table 11. Descriptive statistics of 1836 patients with mandibular or/and midfacial fractures (Modified from Study III).

Variable	Number of patients	%
Age		
Mean	50.6	
Range (years)	18.0–102.5	
Sex		
Male	1280	69.7
Female	556	30.3
Type of facial fracture		
Exclusively midfacial	1371	74.7
Exclusively mandibular	360	19.6
Combined midfacial and mandibular	105	5.7
Associated injury (AI)		
Yes	641	34.9
No	1195	65.1
Type of AI		
AI outside the head and neck	295	16.1
Associated cranial fracture	278	15.1
Associated neck injury	104	5.7
Energy of injury		
High	309	16.8
Anticoagulant therapy	236	12.9
Traumatic brain injury		
Yes	365	19.9

Abbreviations: AI, associated injury

Table 12 shows the association between the presence of TBI and controlled variables. Patients with TBI were older on average, compared to those without TBI (mean age 55.0 vs. 49.5 years). High-energy trauma mechanism was significantly more common in patients with TBI present. With regard to facial fracture type,

patients with exclusively mandibular fractures had the lowest TBI rate (8.6%), while those with combined mandibular and midfacial fractures had the highest TBI rate (25.7%). Significant difference was observed in the type of facial fracture between patients with and without associated TBI. Additionally, anticoagulant therapy was significantly more common in patients diagnosed with TBI.

Table 12. Distribution of controlled variables in 365 patients with TBI present and 1471 patients with TBI absent (Modified from Study III).

Variable	TBI present Number of patients (% of 365)	% of n	TBI absent Number of patients (% of 1471)	% of n	P-value
All (n=1836)	365	19.9	1471	80.1	
Age					
Mean	55.0		49.5		<.0001*
Sex					NS**
Male (n=1280)	260 (71.2)	20.3	1020 (69.3)	79.7	
Female (n=556)	105 (28.8)	18.9	451 (30.6)	81.1	
Type of facial fracture					<.0001**
Exclusively midfacial (n=1317)	307 (84.1)	22.4	1064 (72.3)	77.6	
Exclusively mandibular (n=360)	31 (8.5)	8.6	329 (22.4)	91.4	
Combined midfacial and mandibular (n=105)	27 (7.4)	25.7	78 (5.3)	74.3	
Energy of injury, high (n=309)	122 (33.4)	29.7	187 (12.7)	60.5	<.0001**
Anticoagulant therapy,yes (n=236)	70 (19.2)	29.7	166 (11.3)	70.3	<.0001**

* Wilcoxon test, ** χ^2 test

Table 13 shows the calculation of risk ratio by TBI between each primary predictor present or absent. The risk of TBI was significantly increased in patients presenting with concomitant cranial fractures or neck injuries. Injuries outside the head and neck did not significantly contribute to TBI risk.

Table 13. Calculation of risk ratio (RR) by traumatic brain Injury (TBI) (Modified from Study III).

Variable	TBI present n=365 (% of n)	TBI absent n=1471 (% of n)	Total n=1836 (% of n)	RR (95% CI)	P-value
Associated cranial fracture				4.7 (4.0–5.5)	<.0001
Present	166 (45.5)	112 (7.6)	278 (15.1)		
Absent	199 (54.5)	1359 (92.4)	1558 (84.9)		
Associated neck injury				2.1 (1.6–2.7)	<.0001
Present	41 (11.2)	63 (4.2)	104 (5.7)		
Absent	324 (88.8)	1408 (95.7)	1732 (94.3)		
AI outside the head and neck				0.9 (0.7–1.2)	NS
Present	55 (15.1)	240 (16.3)	295 (16.1)		
Absent	310 (84.9)	1231 (83.7)	1541 (83.9)		

The summary of multivariable logistic regression analysis for TBI is presented in Table 14. The presence of cranial fractures increased the odds for TBI over tenfold. The association between associated neck injury and TBI remained statistically non-significant in the multivariable logistic regression analysis. In addition to associated cranial fracture, other significant predictors for TBI included high-energy trauma mechanism, the use of medication which predisposes to bleeding and advancing age. The fracture pattern also influenced TBI likelihood, with patients sustaining combined mandibular and midfacial fractures exhibiting the greatest odds for TBI.

Table 14. Summary of multivariable logistic regression analysis for traumatic brain injury (TBI) (Modified from Study III).

Variable	OR(95% CI)	P–value
AI outside the head and neck	1.4 (0.9–2.0)	NS
Associated cranial injury	10.7 (7.6–14.9)	<.0001
Associated neck injury	1.6 (0.9–2.6)	NS
Age*		.0004
at 25 yrs old	1.4 (1.2–1.7)	
at 40 yrs old	1.8 (1.3–2.4)	
at 55 yrs old	2.1 (1.4–3.3)	
at 70 yrs old	3.3 (1.6–4.6)	
at 85 yrs old	3.3 (1.7–6.4)	
Type of facial fracture		.0015
Exclusively midfacial	1.9 (1.3–3.9)	
Exclusively mandibular	ref	
Combined midfacial and mandibular	2.9 (1.5–5.4)	
Energy of injury, high	2.5 (1.8–3.5)	<.0001
Medication predisposing for bleeding, yes	2.1 (1.4–3.3)	.0003

Abbreviations: AI=associated injury, OR=odds ratio, CI=confidence interval
*Odds ratio per year 1.014 (95% CI 1.007–1.021)

5.4 Study IV

Among the 253 facial fracture patients with concomitant TBI, the rate of mTBId was 7.1%. Table 15 presents the descriptive statistics of the 18 patients with mTBId. The majority of the 18 patients suffering mTBId were male. All of the patients were involved in an other than high energy injury, fall at ground level being the most common mechanism of injury and exclusively mandibular fracture the most common type of facial fracture. Three patients sustained AIs outside the head and face.

Table 15. Descriptive statistics of 18 patients with mTBId (Own table).

Variable	Number of patients	%
Sex		
Male	15	83.3
Female	3	16.7
Age Group (years)		
Adults (<65)	6	33.3
Elderly (≥65)	12	66.7
Mechanism of trauma		
Fall at ground level	12	66.7
Assault	3	16.7
Fall from height or stairs	0	0.0
Traffic	1	5.6
Other/unknown	2	11.1
Type of facial fracture		
Exclusively mandibular	10	55.6
Combined	3	16.7
Exclusively midfacial	4	22.2
Exclusively upper third	1	5.6
Energy of injury		
Other than high	18	100.0
AI outside the head and face (yes)	3	16.7
Alcohol intoxication	6	33.3
Medication predisposing to bleeding	8	44.4

The distribution of controlled variables by the presence or absence of mTBId is presented in Table 16. Missed TBI diagnoses were significantly more common in patients involved in other than high-energy trauma mechanisms, particularly ground level falls. Additionally, the use of medication predisposing patients to bleeding was significantly associated with mTBId.

Table 16. The distribution of controlled variables by the occurrence of missed traumatic brain injury diagnosis at primary evaluation (mTBId) (Modified from Study IV).

Variable	mTBId present Number of patients (% of 18)	mTBId absent Number of patients (% of 235)	P-value
Sex			NS*
Male	15 (83.3)	157 (66.8)	
Female	3 (16.7)	78 (33.2)	
Mechanism of trauma			.0100*
Fall on ground level	12 (66.7)	78 (33.2)	
Traffic	1 (5.6)	60 (25.5)	
Fall from height or stairs	0 (0.0)	43 (18.3)	
Assault	3 (16.7)	37 (15.7)	
Other/Unknown	2 (11.1)	17 (7.2)	
Type of facial fracture			NS*
Exclusively mandibular	10 (55.6)	148 (63.0)	
Combined	4 (2.2)	48 (20.4)	
Exclusively midfacial	3 (16.7)	20 (8.5)	
Exclusively upper third	1 (5.6)	19 (8.1)	
AI outside the head and face, yes	3 (16.7)	75 (31.9)	NS*
Number of affected organ systems outside the head and face			NS*
0	15 (83.3)	160 (68.1)	
1	2 (11.1)	46 (19.6)	
2	1 (5.6)	25 (10.6)	
3	0 (0.0)	4 (1.7)	
≥4	0 (0.0)	0 (0.0)	
Energy of injury, high	0 (0.0)	51 (21.7)	.0284*
Medication predisposing to bleeding, yes	8 (44.4)	55 (21.7)	.0467**
Alcohol involved (Yes)	6 (33.3)	90 (38.3)	NS**

Abbreviations: AI; associated injury
* Fisher´s exact test
**χ^2 test

When compared to the younger adults, the elderly (at least 65 years of age) exhibited a nearly three-fold risk of mTBId (Table 17). Table 18 summarizes the logistic regression analysis for mTBId. In the unadjusted model, elderly patients had significantly higher odds for mTBId compared to younger adults, though this association was not significant after adjustement for confounders. Ground-level falls were significantly associated with mTBId in the unadjusted analysis, with a borderline non-significant trend in the adjusted analysis.

Table 17. Calculation of risk ratio (RR) by age group between patients with and without missed traumatic brain injury diagnosis (mTBId) at primary evaluation.

Age group (years)	Patients with mTBId at primary evaluation n=18 (% of n)	Patients without mTBId at primary evaluation n=235 (% of n)	Total n=253 (% of n)	RR (95% CI)	P-value
Adults (<65)	6 (33.3)	141 (60.0)	147 (58.1)	ref	
Elderly (≥65)	12 (66.7)	94 (40.0)	106 (41.9)	2.8 (1.1–7.2)	.0349

Table 18. Summary of the logistic regression analysis for missed traumatic brain injury diagnosis at primary evaluation (mTBId) (Modified from Study IV).

Variable	OR(95% CI) unadjusted	P-value	OR(95% CI) adjusted*	P-value
Age Group(yrs)				
Elderly (≥65)	3.0 (1.1–8.3)	.0337	1.6 (0.5–5.4)	NS
Adults (<65)	ref		ref	
Sex				
Male	2.5 (0.7–8.8)	NS		
Female	ref			
Mechanism of trauma				
Fall on ground level	4.0 (1.5–11.1)	.0073	2.9 (0.9–9.3)	NS
Other than fall on ground level	ref			
Type of facial fracture		NS		
Exclusively mandibular	1.3 (0.2–3.4)	NS		
Combined	1.6 (0.2–15.1)	NS		
Exclusively midfacial	2.9 (0.3–29.8)	NS		
Exclusively upper third	ref			
AI outside the head and face				
Yes	ref			
No	2.3 (0.7–8.3)	NS		
No of affected organ systems outside the head and face				
0	2.7 (0.3–21.4)	NS		
1	1.3 (0.1–14.5)	NS		
≥2	ref			
High energy of injury	NA			
Medication predisposing to bleeding				
Yes	2.6(1.0–7.0)	NS	1.4(0.4–4.3)	NS
No	ref			
Alcohol involved				
Yes	ref			
No	1.2(0.5–3.4)	NS		

*adjusted for mechanism of trauma and medication predisposing to bleeding

6 Discussion

6.1 Methodological considerations

The retrospectively analyzed study populations comprised a total of 2682 patients in Study I, 753 patients in Study II, 1836 patients in Study III and 253 patients in Study IV. The patient groups of 1931 adults and 751 elderly (Study I), 33 patients with BCVI and 720 patients without BCVI (Study II), 365 patients with TBI present and 1471 patients with TBI absent (Study III) and 18 patients with mTBId and 235 patients without mTBId (Study IV) were found to be sufficiently large to demonstrate statistical differences between the groups.

The most important limitation of the present study is its retrospective nature. Due to potential deficiencies in patient record documentation, information such as the influence of alcohol at the time of the injury may be underestimated. The influence of alcohol at the time of the injury was assessed based on prehospital care forms and hospital admission records, and it was interpreted as negative if no information was found in the patients documentation. After the initial assessment and treatment some patients were transferred to other hospitals for recovery and follow-up, hence the follow-up time in these cases is very limited and information on the mortality after hospitalization in our unit is lacking. In addition, the study considered as TBIs only those cases where intracranial injuries were detected via imaging. Including mild TBIs proved too challenging and unreliable, as documentation of clinical findings related to possible mild TBI was incomplete. As a result, also the rates of associated TBI were likely underestimated.

Also for the above-mentioned reasons, trauma classification systems were not used in this study. However, the severity of injuries was assessed by classifying patients based on the number of associated injuries and the affected organ systems, which the author of this study considers provides a sufficiently accurate assessment of injury severity for the purposes of this study.

The strengths of this study include its ability to identify significant clinical risk factors for AIs in patients with facial fractures. The results underlined an increased risk of more frequent and more severe AIs in elderly patients and highlighted differences in injury mechanisms and types between adults and the elderly. In addition, the study revealed that the enhanced Denver criteria, currently used for

screening BCVIs, are somewhat inadequate in patients with facial fractures and that even in low-energy injuries, the risk of BCVI should not be underestimated in craniofacial fracture patients. Additionally, the study revealed that a substantial number of TBIs in facial fracture patients go undetected in the early stages. These findings are clinically important and strongly support that patients with facial fractures should be assessed and treated in multidiscplinary units. Moreover, the results increase awareness of the high prevalence of AIs in facial trauma patients, some of which are severe. By recognizing the clinical risk factors identified in this study, AIs can potentially be diagnosed and treated more rapidly, thus improving the overall prognosis.

6.2 Incidence of associated injuries in facial fracture patients

The reported incidence of AIs in the literature varies considerably, largely due to differences in how AIs are defined across studies. In addition, geographical and cultural differences, such as variations in traffic laws and behavior also influence the incidence and types of AIs.

According to this study, 31.8% of patients diagnosed with facial fractures at Helsinki University Hospital between 2013 and 2018 were found to have at least one AI (Study I). A recent study by Färkkilä et al. reported AIs in 20% of facial fracture patients, which is a slightly lower incidence compared to the findings of the present study (Färkkilä et al., 2024). This difference may be partly explained by the fact that university hospitals tend to receive more severely injured patients directly, in contrast to central hospital units. In addition, examining protocols for trauma patients may vary between trauma units of different levels. In our unit, every patient with a facial fracture is also examined by an orthopedic trauma surgeon and, if necessary, by representatives of other specialties, such as neurosurgery. Similarly, a study conducted by Ghosh et al. in a lower level trauma center, reported an AI rate which was notably lower (11.1%) compared to the present study (Ghosh and Gopalkrishnan, 2023). On the other hand, Wusiman et al. reported an incidence of 47.7% of AIs in facial fracture patients, which was higher than in the dataset of the present study (Wusiman et al., 2020). In the present study, dentoalveolar injuries, mild TBIs with only clinical symptoms, and minor soft tissue injuries were excluded, which may partly explain the lower proportion of AIs. Nonetheless, professionals encountering facial fracture patients need to keep in mind that a significant proportion of facial fracture patients suffer from concomitant injuries.

In this study, the most common associated injury was TBI, observed in 15.1% of the patients. Nearly one-third of all AIs encountered in the present study, were TBIs (Study I). Several recent studies have reported higher rates of TBIs in facial fracture

patients compared to the current study. Grant et al. reported an overall concomitant TBI rate of 67% in facial fracture patients, and 35% of the patients having documented TBI findings in imaging (Grant et al., 2012). The notable difference in results may be partly related to the rather small patient population of 100 patients and a relatively short 9-month period of study, compared to 2682 patients and a six year study period in this study. Moore et al. on the other hand found that one third of facial fracture patients experienced TBI-related symptoms during follow-up (Moore et al., 2024). As the retrospective nature of this study made it very challenging to consider cases with only clinical symptoms without findings in imaging as TBIs, a potentially large group of patients with minor TBIs were not reported. This quite possibly has led to underestimation of TBI incidence in the present study. The likely underestimate in TBI incidence even more highlights the risk of concomitant TBI in facial fracture patients and underlines the need to carefully rule out TBI in the context of a facial fracture. Frequent clinical evaluation for possible signs of TBI is crucial, as possible mild injuries may not be detected on imaging. After the acute hospitalization period, follow-up with comprehensive information and provision of support at the brain injury outpatient clinic is beneficial for patients with TBI-related symptoms.

6.3 Risk factors for associated injuries in facial fracture patients

The present study revealed that AIs significantly correlate with a severe type of facial fracture and high energy trauma. Fractures of exclusively upper third and combined facial fractures multiplied the odds for AI when compared to exclusively mandibular and midfacial fractures. High energy injury mechanisms such as MVAs and falls from height correlated strongly with the presence of AIs. (Study I). These findings are consistent with previous research (Scherbaum Eidt et al., 2013; Thorén et al., 2010).

A significant association was also found between age and the presence of AIs. The elderly patients were nearly twice as likely (OR 1.9, 95% CI 1.5-2.5, $p<.001$) to present with associated injuries as compared to younger adults (Study I). Similar results have been reported in previous literature. Toivari et al. reported an adjusted odds of 2.4 ($p<.001$) for AIs in geriatric facial fracture patients compared with younger controls (Toivari et al., 2016). Diab et al. on the other hand reported an odds for AIs as high as 3.6 ($p<.05$) in the elderly patients (Diab et al., 2022).

When considering the relationship between facial fractures and concomitant TBI, this study provides important insights, emphasizing the impact of AIs in the head and neck region. The findings reinforce earlier observations that TBI frequently co-occurs with facial fractures and that the presence of associated cranial fractures

or neck injuries significantly increase the likelihood of TBI (Study III). However, while the study confirmed a significant association between TBI and associated injuries in the head and neck, a clinically significant incidence of concomitant TBI (10.9%) was also reported in facial fracture patients without other AIs (Study III).

The demographic findings for concomitant TBI also align with emerging epidemiological trends. While young males subjected to high-energy trauma have traditionally dominated TBI statistics, the aging population is reshaping this pattern (Capizzi et al., 2020; Peeters et al., 2015). The findings may perhaps be partly explained by the improved availability of CT imaging over the past decades and thus possibly by an overall increase in imaging. However, the observation that nearly two-thirds of TBIs in this study occurred after mechanisms other than high-energy trauma (Study III), supports the transition that underlines the need to recognize low-energy falls as significant contributors to neurotrauma within facial fracture patients, especially in elderly patients with comorbities and polypharmacy.

6.4 Incidence and characteristics of blunt cerebrovascular injuries in craniomaxillofacial fracture patients

Recent literature reveals that patients suffering craniofacial trauma are at increased risk of BCVI (Varjonen et al., 2018; Weber et al., 2018). In this study, BCVIs were encountered in 4.4% of the 753 craniofacial fracture patients. The rate is notably lower than in the study by Varjonen et al., which revealed a BCVI rate of 18.6% in craniofacial fracture patients. However, Varjonen et al. studied a cohort consisting only of suspected polytrauma patients who underwent a CT of the whole body (Varjonen et al., 2018). Similarly, this study demonstrates that craniofacial fracture patients who have sustained high-energy trauma, particularly those involved in MVAs, are at a significantly increased risk of sustaining BCVIs. However, noteworthy in the current study, BCVIs alco occurred in patients with low-energy injury mechanisms, representing half (51.5%) of the BCVIs. In total, a BCVI was detected in 3.0% of the CTA screened patients involved in other than high energy trauma. With regard to BCVI risk, minor low-energy facial fractures should not be underestimated either, as sudden head rotation and cervical hyperextension are still possible in these cases (Murabit and Tredget, 2012).

When examining the incidence of BCVI by fracture subtype, a significantly higher rate (8.7%) was discovered in isolated cranial fracture patients. This elevated risk of BCVI among cranial fracture patients has also been recognized in earlier literature (Miller et al., 2001; Mutze et al., 2005). The present study demonstrated, that in 553 patients with isolated facial fractures, the rate of BCVI was as high as 3.1% (Study II). Similar findings, indicating that the risk of BCVI associated with

facial fractures is higher than previously assumed, have been reported in recent international multicenter study (Weber et al., 2018).

Importantly, the present study revealed that BCVIs were also detected in patients not meeting the extended Denver criteria. The three patients with BCVI, not meeting the screening criteria, sustained unilateral zygomatic-maxillary-orbital fractures and/or frontal bone fractures. This raises a critical question of whether we are overlooking clinically significant vascular injuries due to insufficient screening sensitivity. While overly broad use of imaging strains the healthcare resources and exposes patients to unnecessary radiation, under-screening risks missing potentially disabling or fatal ischemic events. It is also important to consider whether imaging actually provides added value in guiding treatment decisions. For instance, in patients who are already on therapeutic anticoagulation prior to the injury, screening for BCVI through imaging may offer limited clinical benefit, as the findings are unlikely to alter the management strategy. This highlights the need to tailor imaging protocols not only to the anatomical and mechanistic risk factors but also to the individual patient´s pre-existing treatment context.

According to the present study, the majority (69.2%) of BCVIs identified in CTA imaged craniofacial fracture patients, were located in the carotid arteries. In previous studies, carotid artery injuries have been proportionally less common, with up to half of all BCVIs involving the vertebral arteries (Hwang et al., 2010; Kazemi et al., 2012). In addition, the present study demonstrated that patients with craniofacial fractures more commonly sustain BCVIs of the upper cervical level (between cervical planes of C0 and C2). This is most probably related to the fact that craniofacial fractures are often associated with multidirectional rotation of the head and cervical spine, which can stretch the vascular structures at the occipito-cervical junction and across the upper cervical spine levels. In this study, BCVIs were located at upper cervical levels in approximately 75% of cases, which is a higher proportion when compared to BCVI patients in general. In comparison, the study by Bensch et al., which examined a broader population of high-energy trauma patients, reported that 64% of BCVIs were located at upper cervical levels (Bensch et al., 2019). Thus, according to the current study, BCVIs in patients with craniofacial fractures most commonly involve the carotid arteries at the C0-C2 cervical levels.

6.5 Age related considerations

Physiological and cognitive changes associated with aging, along with comorbities and long-term medications, make elderly individuals a distinct subgroup among trauma patients. Reflecting the progressive aging of Western populations, the proportion of elderly patients with facial fractures has been rising sharply. In this study, elderly patients accounted for 28% of the cohort (Study I), whereas in previous

studies conducted in our institution, the corresponding proportions were 6.6% in 1981 (Kontio et al., 2005), 9.8% in 1997 (Kontio et al., 2005), and 11% in 2003-2004 (Thorén et al.,2010). Similar findings have been reported by Kloss. et al., whose study showed that the proportion of elderly patients had almost doubled from 1991 to 2003 (Kloss et al., 2007). In the study by Yamamoto et al., the proportion of elderly patients increased from 5.7% to 19.4% between the years 1981 and 2010 (Yamamoto et al., 2011b).

The significant increase in elderly patients presents a challenge for professionals treating facial fractures, as the injury types and mechanisms in this age group differ from those seen in younger populations. When managing elderly patients, it is essential to consider age-related characteristics and the distinct fracture patterns that often differ from those typically observed in younger individuals. According to the current study, 63.8% of facial fractures in elderly patients were caused by falls at ground level, whereas in younger adults, the most common cause was assault. Regarding fracture types, elderly patients had a significantly higher incidence of midfacial fractures compared to younger adults (Study I). A recent European multicenter study by Brucoli et al., reported similar findings (Brucoli et al., 2020). In addition, they reported a high involvement (55%) of female patients among elderly facial fracture patients. This aligns with the findings of the present study, in which 50.6% of the elderly patients were female (Study I).

As previously mentioned, the present study identified older age as a significant predictor for AIs in patients with facial fractures. AIs were observed in 43.9% of patients aged 60 or older and in 44.8% of those over 70 years old. However, in the multicenter study by Brucoli et al., AIs were observed in 27.3% of patients aged 70 years or older, which is clearly a lower figure compared to this study. On the other hand, Toivari et al. reported a rate of 44.0% of AIs in elderly facial fracture patients aged at least 65 years (Toivari et al., 2016). The differences in results are likely partly related to variations in patient populations regarding general health conditions and medications, as well as differing trauma mechanisms. There are also likely differences between units in the examining protocols for facial fracture patients. In the present study, all patients were examined not only by an oral and maxillofacial surgeon but also by an orthopedic trauma surgeon, and when necessary, by specialists from other fields, such as neurosurgery.

The current study reported that elderly patients where more severely injured, as their odds for injuries in 2 or more organ systems was 1.8-fold when compared to younger adults ($p<.001$). Parallel to findings of the current study, Toivari et al. reported that geriatric patients´ risk for multiple AIs and polytrauma is significantly higher when compared to younger adults (Toivari et al., 2016). Additionally, in the current study, the odds for mortality was 6.8 times higher compared to younger adults ($p<.001$), with the mortality rate of the elderly being 3.3%. Similarly,

Spaniolas et al. reported that the 4.4% mortality rate among the elderly trauma patients was significantly higher than the mortality rate among younger adults (Spaniolas et al., 2010). The higher mortality risk among elderly facial fracture patients can be partly explained by pre-existing comorbities and multiple medications, as well as the higher risk of AIs, particularly more severe and multi-system AIs. Another factor leading to increased mortality may be the undertriage of elderly trauma patients.

6.6 Risk of undertriage for traumatic brain injury in facial fracture patients

The present study revealed an incidence of mTBId as high as 7.1%, which is clinically relevant (Study IV). Several explanatory factors may underlie this rate. Prior research has underscored the pivotal role of the examining physician´s specialty in determining the likelihood of TBI detection, with non-neurological specialties being associated with a higher rate of diagnostic oversight (Davidoff et al., 1988; Puljula et al., 2012). These findings underscore the importance of initial evaluations taking place in trauma centers equipped with multidisciplinary expertise. Our data further indicate that TBIs were most frequently missed in patients who lacked additional concomitant injuries, potentially because these cases do not trigger the same level of diagnostic scrutiny.

Diagnostic challenges were particularly pronounced among older patients who sustained injuries through other than high energy mechanisms, such as ground-level falls. In contrast, TBIs associated with high-energy trauma were rarely overlooked (Study IV). This is likely attributable to such patients being swiftly triaged to higher-level trauma centers with standardized imaging protocols and multidisciplinary evaluation. Conversely, individuals with minor trauma are often routed through less specialized systems, where imaging decisions rely more heavily on subjective clinical judgment than on protocol-driven assessment.

This study demonstrates a mTBId incidence of 11.3% among elderly patients. Eldely patients were found to have a nearly threefold increased risk of mTBId compared to younger adult cohorts (Study IV). Although this elevated risk persisted in the multivariate analysis, the association did not reach statistical significance, suggesting that further investigation with larger sample sizes may be warranted to clarify this relationship. The phenomenon of undertriage is well-documented in emergency medicine, with elderly patients being especially vulnerable to diagnostic inaccuracies (Kodadek et al., 2015). The presence of comorbidities and pre-injury anticoagulant use among older adults further compounds their susceptibility to serious complications from otherwise seemingly minor mechanisms of injury. This has been corroborated by earlier studies demonstrating elevated mortality rates in

elderly individuals experiencing ground-level falls with initially subtle neurological impairment (Hartshorne et al., 1997; Spaniolas et al., 2010; Sperry et al., 2006; Thamminaina et al., 2022; Velmahos et al., 2001). Also in our cohort, ground-level falls represented the most frequent injury mechanism and were overwhelmingly seen in older adults – significantly increasing the likelihood of mTBId in this subgroup. However, it is critical to note that mTBId was also detected among younger patients, albeit at a lower rate (4.1%) (Study IV). This finding underscores the necessity for all clinicians treating facial fractures, regardless of the patient´s age, to maintain a high index of suspicion for TBI and to seek specialized consultation readily when indicated.

Importantly, our findings suggest that diagnostic delays were primarily attributable to a failure to suspect TBI and insufficient initial imaging. In most cases, facial fractures were diagnosed prior to the eventual identification of TBI. Among the various types of facial fractures, isolated midfacial fractures were most commonly associated with mTBId. The time between the initial evaluation and eventual TBI diagnosis varied substantially, ranging from several hours to nearly two weeks.

Alcohol intoxication was documented in approximately 38% of the study population at the time of the injury. While it is conceivable that alcohol-related symptoms could mask or mimic signs of neurological impairment, our analysis did not find a significant association between intoxication and mTBId. This aligns with existing literature indicating that alcohol does not significantly confound GCS assessments in a clinically meaningful way (Sperry et al., 2006; Thamminaina et al., 2022).

6.7 Future prospects

Education about the prevalence and risk factors of AIs should be emphasized for healthcare professionals encountering patients with facial fractures; every facial fracture patient, even with low-energy injuries or minor fractures are at risk of sustaining potentially severe concomitant injuries and should be evaluated by a multidisciplinary team. Elderly patients in particular must be carefully assessed regardless of the level of the injury energy or the type of the facial trauma.

To gain more detailed information about the risks for AIs in facial fracture patients, prospective research is required. An evaluation protocol based on high quality research data is needed to improve the prognosis of facial fracture patients with AIs and to reduce the potentially devastating consequences of late detection of AIs.

In addition, artificial intelligence combined with large-scale registry studies could possibly facilitate the development of more accurate predictive models. The

models could take into account fracture morphology, trauma mechanism and the patient´s overall clinical profile. This could optimize imaging strategies to detect for example TBIs and BCVIs associated with facial fractures and thus enhance patient safety.

7 Summary/Conclusions

The hypotheses of the present study were confirmed. The following key findings and conclusions were revealed by this study:

1. AIs in general and associated TBI in particular are frequent among patients with facial fractures. AIs are significantly more common among elderly facial fracture patients. The elderly also have greater odds for AIs to 2 or more organ systems and mortality when compared to younger adults.

2. BCVIs frequently occur in craniomaxillofacial fracture patients. High-energy injuries, particularly MVAs, and isolated cranial fractures are significantly associated with BCVIs, but these injuries also occur during minor traumas and in patients with isolated facial fractures. Thus, facial fractures that occur in association with BCVI do not consistently fulfil the Denver screening criteria, therefore these criteria should be further evaluated to ensure that lower-energy injuries and a broader range of facial fracture patterns are adequately recognized.

3. Significant risk factors for facial fracture-related TBI are concomitant injuries in the head and neck region, particularly cranial fractures. In addition to increasing age, high energy injury mechanism and medication predisposing to bleeding significantly predict the risk of associated TBI.

4. Facial fracture patients, particularly elderly patients sustaining other than high energy injury mechanisms are at significant risk of delayed diagnosis of concomitant TBI.

5. To detect and minimize the consequences of AIs related to facial fractures, emphasizing a multidisciplinary team and carefully considering risk factors associated with AIs is of primary importance. The high-risk patients should be repeatedly clinically evaluated to exclude AIs such as TBIs and BCVIs with potentially devastating consequences.

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