# Traumatic Brain Injuries and Whiplash Injuries

## Epidemiology and Long-Term Consequences

**Johan Styrke**


**Department of Surgical and Perioperative Sciences, Surgery and**
**Department of Community Medicine and Rehabilitation, Rehabilitation Medicine**

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***Till Maria, Eldar och Helmer***

*Om man går fort, fort*
*och tittar rakt fram*
*då kommer man fort fram*

*Om man går långsamt*
*och tittar på allt vid vägkanten,*
*om man tar upp en sten*
*och luktar på en blomma*
*då går det inte fort*

*Men stenen och blomman*
*har blivit ens vänner*

Kaj Beckman

Barnens Versbok, 1986
Isbn:91-7448-713-2

# Preface

The head and neck are closely connected and are often simultaneously affected in traumatic events. Injury is sometimes evident when an intracranial bleeding or a neck fracture is encountered, but as of today, in the majority of cases of traumatic brain injuries and whiplash injuries, no objective finding verifies that actual tissue damage has occurred. The natural course of recovery in both traumatic brain injuries and whiplash injuries is that symptoms disappear within weeks to months. Still, some persons experience long-term symptoms and disability. Why is that? What can we do about it? These are the key questions within the field of research on traumatic brain injuries and whiplash injuries.

I am proud to add a small piece to the puzzle through the publication of this thesis. It provides original data on the epidemiology of traumatic brain injuries and whiplash injuries along with data on the frequency of subsequent long-term symptoms, disability and life satisfaction.

Johan Styrke, 2012

# Table of Contents

# Abstract


**Background**
The incidence of traumatic brain injuries (TBI) is about 500 cases per 100,000 inhabitants per year, a majority of which are mild TBI (MTBI). The incidence of whiplash injuries is about 300/100,000/year. There are several similarities between MTBI and whiplash injuries with regard to the causes of injury (traffic crashes and falls), the demographic profile of the injured (mostly young persons), and the type of symptoms exhibited by some of the injured (for example head/neck pain, fatigue, irritability, impaired cognitive functioning, and depression).

**Main aim**
To investigate the epidemiology and long-term consequences in terms of symptoms, disability, and life satisfaction in cases of TBI and whiplash injuries in a well-defined population.

**Material and methods**
Data on frequencies and characteristics of TBI and whiplash injuries were extracted from the injury database at the emergency department (ED) of Umeå University Hospital (UUH). The results were presented as descriptive epidemiology.

The 18-65 year-old persons who sustained an MTBI or whiplash injury in 2001, were provided a questionnaire three and five years after injury respectively, in which questions were asked about:

- Symptoms; Rivermead Post Concussion Symptoms Questionnaire (RPQ)
- Disability; Rivermead Head Injury Follow Up Questionnaire (RHFUQ)
- Life satisfaction; LiSat-11

A local reference population was used for comparison of the RPQ. A national cohort was used as reference for LiSat-11. Data on sick leave for the cases of whiplash injuries were analysed to calculate the cost to society for loss of productivity.

**Results**
In 2001, the incidence of TBI was 354/100,000/year. The mean age was 23 and 55% were men. Ninety-seven percent of the injuries were classified as mild (Glasgow coma scale 13-15). The main causes were falls (55%) and traffic related injury events (30%). In 8% of the cases (17% of the elderly persons) an intracranial bleeding was detected by using CT.

The 3-year follow-up of the MTBI patients showed that women had more symptoms and disability (~50%) than men (~30%). Both women and men had more symptoms and lower life satisfaction compared with the reference population.

The incidence of traffic-related whiplash injuries in adults was 235/100,000/year and the annual incidences were relatively stable during 2000-2009. Combining the incidences with national insurance data showed that the proportion of insurance claims decreased during the period.

When looking at whiplash trauma following all causes of injury in 2001, traffic crashes caused 61% of the injuries and falls caused 14%. Neck fractures occurred in 3% of the cases.

Five years after whiplash injury, the injured persons had more symptoms and lower life satisfaction than the references. Sick leave ≥15 days was granted in 14% of the cases of whiplash injuries. The median number of sick days was 298 and the cost of loss of productivity during the follow-up was 5.6 million USD.

The frequencies of symptoms were relatively alike when comparing subjects with whiplash injuries to subjects with MTBI.

**Conclusion**

TBI and whiplash injuries are common, especially among young people, and the injuries render long-term symptoms, disability, and impaired life satisfaction in up to 50% of the cases. Symptoms exhibited are alike between the two types of injuries. The cost to society for loss of productivity is high, and there is a need for enhanced preventive measures aiming at reducing traffic-related injuries, sports injuries, alcohol-related injuries, and falls. Physical, mental, and social factors are important and should be addressed when examining and treating patients with persisting symptoms following TBI and whiplash injuries.

**Keywords**

Traumatic Brain Injuries; Whiplash Injuries; Epidemiology; Follow-up Studies; Cohort Studies

# Sammanfattning (Summary in Swedish)

**Bakgrund**
Skallskador utgör ett stort folkhälsoproblem, särskilt eftersom många som skadas är unga. Skallskador är också, parallellt med självmord, den vanligaste dödsorsaken hos ungdomar och unga vuxna. De flesta av skadorna klassas som ”lätta” i akutskedet men trots det så kommer en del av patienterna att drabbas av kvarstående besvär, t ex smärta, koncentrationssvårigheter, depression och nedsatt livstillfredsställelse.

Whiplashskador är nästan lika vanligt förekommande som skallskador och uppkommer framförallt i trafikolyckor. Även fall- och sportskador orsakar emellertid ett betydande antal whiplashskador. I normalfallet avtar de akuta symptomen inom några veckor men en del av patienterna anger att de får kvarstående besvär. Ett flertal skademekanismer i nackens vävnader är kända men tyvärr svåra att verifiera eller utesluta.

**Huvudsyfte**
Att undersöka förekomsten av skallskador och whiplashskador i en väldefinierad population samt beskriva restsymptom, funktionsnedsättningar och livstillfredsställelse hos de drabbade tre till fem år efter skadan.

**Material och metod**
*Förekomsten av skadorna (Studie I, III och IV)*
Studierna baseras på skadedatabasen vid Norrlands Universitetssjukhus i Umeå (NUS). I skadedatabasen registreras alla patienter som söker till akutmottagningen efter en skadehändelse, ca 10 000 fall per år. När patienterna anmäler sig i receptionen tilldelas de en skadejournal som de själva fyller i i väntan på att bli undersökta. När patienter inkommer med svårare skador får anhöriga i möjligaste mån fylla i journalen. Primärvårdens jour har under åren för studiens genomförande varit belägen på akutmottagningen under kvällar, nätter och helger vilket inneburit att de få skadefall som konsekvent missats har varit lättare skador som behandlats dagtid på vårdcentralerna i upptagningsområdet.

*Långtidsuppföljning (Studie II, III och V)*
En uppföljande enkätundersökning bestående av ett antal validerade frågeformulär skickades till alla skall- och whiplashskadade patienter i arbetsför ålder tre respektive fem år efter skadehändelsen. De frågeformulär som analyserades var:

- För symptom: Rivermead Post Concussion Symptoms Questionnaire (RPQ)

- För funktionsnedsättning: Rivermead Head Injury Follow Up Questionnaire (RHFUQ)
- För livstillfredsställelse: Life Satisfaction-11 (LiSat-11)
- För smärta (hos de whiplashskadade): Visual Analogue Scale (VAS)

Resultaten från RPQ och LiSat-11 jämfördes med sedan tidigare tillgängligt material från åldersmatchade referenspopulationer.

När det gäller de whiplashskadade genomfördes en femårsuppföljning avseende sjukskrivning. Data från Försäkringskassan analyserades och samhällskostnaden för produktionsbortfall beräknades baserat på den genomsnittliga kostnaden för en årsarbetare.

**Resultat**

Förekomsten av skallskador vid NUS under 2001 var 354 skadade per 100 000 invånare. Medelåldern på de skadade var 23 år och 55% var män. Andelen lätta skallskador var 97%. Fallolyckor orsakade flest skador (55%) och trafikolyckor var näst vanligast (30%). Minst 17% av patienterna (ofta medelålders personer) var alkoholpåverkade. Hos 8% av patienterna (17% av personer över 65 år) upptäcktes blödningar i hjärnan.

I uppföljningen efter tre år noterades att de skallskadade patienterna i arbetsför ålder hade högre symptomfrekvens och lägre livstillfredsställelse än referenspopulationerna. Kvinnorna rapporterade högre förekomst av symptom och funktionsnedsättning än männen. Funktionsnedsättning av varierande grad samt så kallat postkommotionellt syndrom (med förekomst av minst tre specificerade symptom) fanns hos ca 50% av kvinnorna och hos ca 30% av männen.

Medelförekomsten av whiplashskador till följd av trafikolyckor var under 2000-2009 235 fall per 100 000 invånare och år. Sammantaget var förekomsten relativt stabil under perioden; en ökning med 1% per år noterades. När siffrorna matchades mot data från Försäkringsförbundet noterades en minskning av andelen försäkringsärenden under perioden.

2001 års incidens av akuta whiplashskador efter alla typer av skadehändelser var 383 skadade per 100 000 invånare. Könsfördelningen var 56% män / 44% kvinnor och medelåldern var 32 år. Trafikolyckor orsakade 61% av whiplashskadorna medan fallolyckor stod för 14%. Frakturer i nacken var ovanliga och hittades hos 3% av patienterna.

I femårsuppföljningen av whiplashpatienter i arbetsför ålder noterades att de hade högre frekvens (ca 50%) av symptom samt lägre livstillfredsställelse än referenspopulationerna. Funktionsnedsättning av varierande grad fanns hos ca 50% av patienterna. Kvinnorna skattade sin smärta högre än männen men i övrigt fanns ingen könsskillnad beträffande förekomsten av symptom, funktionsnedsättning och livstillfredsställelse. Vid jämförelse mellan

whiplashskadade och skallskadade noterades att förekomsten av symptom med några få undantag inte skilde sig åt mellan grupperna.

Fjorton procent av de whiplashskadade blev sjukskrivna i mer än 14 dagar. Sjukskrivningens medianlängd var 298 dagar och i 3% av fallen fortskred sjukskrivningen under hela 5-årsperioden. Trafikskadade sjukskrevs oftare än fallskadade och noterbart är också att nackfrakturer ej resulterade i längre sjukskrivningar än mjukdelsskador. Samhällskostnaden för produktionsbortfall var i snitt ca 600 000 kr per sjukskrivning.

**Konklusion**

Avhandlingen bidrar med nya grunddata som ytterligare förstärker bilden av att skallskador och whiplashskador är vanliga och att det framförallt är unga personer som drabbas. Grad och typ av kvarstående besvär är likartade efter båda skadetyper. Samhällskostnaden för skadorna är hög och lämpliga områden för skadepreventivt arbete tycks vara fallskadeprevention, trafikskadeprevention, skadeprevention inom hästsport, fotboll och ishockey samt prevention av alkoholrelaterade skador.

Både fysiska, psykologiska och sociala faktorer inverkar på läkningsförloppet och symptombilden efter skadorna och det är viktigt att utvärdera och behandla patienterna med utgångspunkt från detta.

# List of publications

I. Styrke J, Stålnacke B-M, Sojka P, Björnstig U. Traumatic Brain Injuries in a Well-Defined Population: Epidemiological aspects and Severity. J. Neurotrauma. 2007 Sep.;24(9):1425–36.

II. Styrke J, Sojka P, Björnstig U, Bylund P-O, Stålnacke B-M. Sex-differences in Symptoms, Disability, and Life Satisfaction three years after Mild Traumatic Brain Injury – A Population-based Cohort study. Submitted.

III. Styrke J, Stålnacke B-M, Bylund P-O, Sojka P, Björnstig U. A 10-Year Incidence of Acute Whiplash Injuries after Road Traffic Crashes in a Defined Population in Northern Sweden. PM&R. 2012 Oct;4(10):739-47.

IV. Styrke J, Stålnacke B-M, Bylund P-O, Sojka P, Björnstig U. Whiplash Trauma – Epidemiology, Long-term Sick leave and its' Costs. Submitted.

V. Styrke J, Sojka P, Björnstig U, Stålnacke B-M. Symptoms, Disability, and Life Satisfaction five years after Whiplash Injury – A Population-based Cohort study. Submitted.

# List of abbreviations

ADL – Activities of daily living
AIS – Abbreviated Injury Scale (1), see definitions
BDI-II – Beck Depression Inventory-II (2) (questionnaire)
CT – Computed Tomography
CWO – Contact With Object
DSM-IV – Diagnostic and Statistical Manual of Mental Disorders, 4th edition (3)
ED – Emergency Department
EH – Epidural Haematoma
GCS – Glasgow Coma Scale (4), see definitions
ICB – Intracranial Bleeding
ICD-10 – International Classification of Diseases (10th revision) (5)
LiSat-11 – Life Satisfaction 11 (6) (questionnaire)
LOC – Loss Of Consciousness
MAIS – Maximum AIS (the highest AIS-score in cases of multiple injuries)
MTBI – Mild Traumatic Brain Injury, see definitions
PCS – Post-Concussion Syndrome, see definitions
PTA – Post-Traumatic Amnesia
PTSD – Post-Traumatic Stress Disorder
QoL – Quality of Life, see definitions
RHFUQ – Rivermead Head Injury Follow Up Questionnaire (7)
RPQ – Rivermead Post Concussion Symptoms Questionnaire (8)
SA – Traumatic Subarachniodal Haemorrhage
SD – Subdural Haematoma
SIF – Swedish Insurance Federation
TBI – Traumatic Brain Injury, see definitions
USD – United States Dollar
UUH – Umeå University Hospital
VAS – Visual Analogue Scale
WAD – Whiplash Associated Disorders, see definitions

# Definitions

## I. Traumatic Brain Injury (TBI)

"TBI is defined as an alteration in brain function, or other evidence of brain pathology, caused by an external force."

The 2010 definition of TBI according to The Demographics and Clinical Assessment Working Group of the International and Interagency Initiative toward Common Data Elements for Research on Traumatic Brain Injury and Psychological Health (9)

## II. Mild TBI (MTBI)

"MTBI is an acute brain injury resulting from mechanical energy to the head from external physical forces. Operational criteria for clinical identification include: (i) 1 or more of the following: confusion or disorientation, loss of consciousness for 30 minutes or less, post-traumatic amnesia for less than 24 hours, and/or other transient neurological abnormalities such as focal signs, seizure, and intracranial lesion not requiring surgery; (ii) Glasgow Coma Scale score of 13–15 after 30 minutes post-injury or later upon presentation for healthcare. These manifestations of MTBI must not be due to drugs, alcohol, medications, caused by other injuries or treatment for other injuries (e.g. systemic injuries, facial injuries or intubation), caused by other problems (e.g. psychological trauma, language barrier or coexisting medical conditions) or caused by penetrating craniocerebral injury."

The 2004 definition of MTBI according to the WHO Collaborating Task Force on Mild Traumatic Brain Injury (10). The definition is a modified version of the 1993 definition of MTBI according to the Mild Traumatic Brain Injury Committee of the Head Injury Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine (11).

## III. Moderate TBI

A TBI with a GCS of 9-12 upon presentation for healthcare

According to the present paradigm (12,13)

## IV. Severe TBI

A TBI with a GCS of 3-8 upon presentation for health care

According to the present paradigm (12,13)

## V. Whiplash trauma and Whiplash injury

"Whiplash [trauma] is an acceleration-deceleration mechanism of energy transfer to the neck. It may result from rear-end or side-impact motor vehicle collisions, but can also occur during diving or other mishaps. The impact may result in bony or soft-tissue injuries (whiplash injury), which in turn may lead to a variety of clinical manifestations (Whiplash-Associated Disorders)."

The 1995 definition of whiplash by the Quebec Task Force on Whiplash Associated Disorders (14)

## VI. Whiplash associated disorders (WAD) grades

- WAD 0: No complaint about the neck, no physical sign(s).
- WAD 1: Neck complaint of pain, stiffness, or tenderness only; no physical sign(s).
- WAD 2: Neck complaint and musculoskeletal sign(s).
- WAD 3: Neck complaint and neurological sign(s).
- WAD 4: Neck complaint and fracture or dislocation.

The 1995 definition of WAD-grades by the Quebec Task Force on Whiplash Associated Disorders (14)

## VII. Chronic whiplash associated disorder (Chronic WAD)

"A whiplash-associated disorder that has lasted for more than 6 months."

The 1995 definition of chronic whiplash injury by the Quebec Task Force on Whiplash Associated Disorders (14)

## VIII. Glasgow Coma Scale (GCS)

**Best eye response**

1, No eye opening; 2, Eye opening in response to pain; 3, Eye opening to speech; 4, Eyes opening spontaneously

**Best verbal response**

1, No verbal response; 2, Incomprehensible sounds; 3, Inappropriate words; 4, Confused; 5, Oriented

**Best motor response**

1, No motor response; 2, Extension to pain; 3, Abnormal flexion to pain; 4, Flexion/Withdrawal to pain; 5, Localizes to pain; 6, Obeys commands

The sum of the three arms is the GCS-score, maximum is 15 and minimum is 3 (4)

## IX. Abbreviated Injury Scale (AIS)

1. Minor
2. Moderate
3. Serious
4. Severe
5. Critical
6. Maximal (currently untreatable)

The Association for Advancement of Automotive Medicine (AAAM) (1)

## X. Post-Concussion Syndrome (PCS) according to ICD-10 (5)

"A syndrome that occurs following head trauma (usually sufficiently severe to result in loss of consciousness) and includes a number of disparate symptoms such as headache, dizziness, fatigue, irritability, difficulty in concentration and performing mental tasks, impairment of memory, insomnia, and reduced tolerance to stress, emotional excitement, or alcohol."

In accordance with the present paradigm, three or more of the listed symptoms are required to set the diagnosis of PCS (15,16)

## XI. Post-Concussion Syndrome (PCS) according to DSM-IV (3)

"A) history of TBI causing "significant cerebral concussion;" B) evidence from neuropsychological testing or quantified cognitive assessment of difficulty in cognitive deficit in attention and/or memory; C) presence of at least three of eight symptoms (e.g., fatigue, sleep disturbance, headache, dizziness, irritability, affective disturbance, personality change, apathy) that appear after injury and persist for 3 months; D) symptoms that begin or worsen after injury or representing a significant worsening of pre-existing symptoms; E) interference with social and or occupational functioning; and F) exclusion of dementia due to head trauma and other disorders that better account for the symptoms."

## XII. Disability

"Disability is a difficulty in functioning at the body, person, or societal levels, in one or more life domains, as experienced by an individual with a health condition in interaction with contextual factors."

Disability according to the Measuring Health and Disability in Europe: Supporting Policy Development (MHADIE) consortium (17)

## XIII. Quality of Life (QoL)

"An individual's perception of his/her position in life in the context of the culture and value systems in which he/she lives, and in relation to his/her goals, expectations, standards and concerns. It is a broad ranging concept, incorporating in a complex way the person's physical health, psychological state, level of independence, social relationships and their relationship to salient features of their environment."

The WHO definition of Quality of Life (18)

## XIV. Life Satisfaction

"Life-satisfaction is the degree to which a person positively evaluates the overall quality of his/her life as-a-whole. In other words, how much the person likes the life he/she leads."

Life satisfaction is a concept underlying QoL. Definition according to Veenhoven (19)

# Background

## History

*Traumatic brain injury*

Traumatic brain injury (TBI) has been known since before modern history (20). Trepanation, in which a hole is drilled into the skull to extract a haematoma, has been known both in the old and the new world for more than 7,000 years. Signs of healing suggests that the surgery could be successful (21). Scientific work on brain injury on the PubMed dates back to 1811 when a case report of a successful brain surgery was published (22). A summary of the "mass of surgical literature" regarding brain injury was published in 1828. Brain concussion was known at this time to produce headache, amnesia, vomiting, sensory deficits, tinnitus, irritability, or furious delirium without evidence of structural damage to the head or brain (23).

Later during the 19th century, reports from war became important sources of knowledge. In the American civil war, death rates reached 70% after a penetrating head injury (20). In World War I (WWI), initial death rates from such injuries were 44-60% after surgery. The rates improved with "modern" surgical techniques at that time including hygienic procedures and the use of antiseptic oils. At the end of WWI, post-operative death rates as low as 29% was reported after brain surgery (24). In World War II, the post-operative mortality after neurosurgery was reduced to about 10% at best (25).

In the 1940s, measurement of the spinal-fluid pressure by means of lumbar puncture was subject for research and in the mid 1950s, continuous intracranial pressure monitoring was introduced by the Swedish professor Nils Lundberg, thus initiating the "modern era" of head injury treatment (26-28). Further improvement of intensive care results of severe TBI was reached when the importance of prevention of shock and brain swelling was recognised (28). In 1970, the so far most important diagnostic tool was introduced – the computed tomography (CT). Suddenly, intracranial haematomas could be differentiated from other causes of impaired consciousness, thereby facilitating clinical decision-making (29).

During the last half of the 20th century, growing traffic caused an increasing number of civilian brain injuries in need of medical care and rehabilitation (30). Along with expanding general health care, cognitive rehabilitation begun to develop and between 1980 and 1995 TBI rehabilitation became a sub speciality under Rehabilitation medicine (30).

From the 1980s, research on TBI has increased rapidly. As of today more than 60,000 papers on TBI have been published in the PubMed database. But has health care improved because of this? The answer is, yes it has. For example, mortality from severe TBI with brain oedema can be reduced by

about 50% when modern treatment is utilized (31,32). There is evidence of mortality reduction and improvement of outcome when hypothermia is used (33). Intensive physiotherapy leads to improved functional abilities (34). Evidence-based protocols for cognitive intervention have been developed (35), and there is evidence that serotonergic antidepressants and cognitive behavioural intervention can be used to treat post-TBI depression (36). Physiotherapy, cognitive intervention, and treatment of depression are examples of interventions that are included in advanced neuro-rehabilitation; an important aspect of modern brain injury health care (37).

*Whiplash injury*

From 1866 to 1882, John Erichsen published substantial material on clinical and mediolegal aspects of "Concussion of the Spine", at that time, also known as "Railway Spine" (38). He concluded that spinal injuries could arise from various reasons but none with the frequency and severity as those injuries arising from railway collisions. He described slowly progressive functional derangements without signs of physical injury and discussed the frequency of litigation as a problem. He made this statement that could as well have originated from the 1990s.

> "I believe that, as these cases come to be more carefully studied, and consequently better understood, much of the obscurity that has hitherto surrounded them will be removed, and we shall less frequently see those deplorable contests of professional opinion which we have been so often obliged to witness in our courts of law" (38)

In France and England, other scientists lay forward the opinion that these cases were a result of hysteria, functional disorder, or general nervous shock (39,40). Crowe launched the term "Whiplash" at a conference in 1928. He later regretted using that term as it came to be used both for the mechanism of injury and the diagnosis itself (41).

Marshall described the first cases of neck injuries following low-speed car-crashes in 1919. Treatment with manipulation, orthopaedic support, exercise, and physiotherapy was recommended (42). In the 1960s, initial rest, preferably with a soft neck collar (which first had been described by Schanz in 1908) followed by active motion was recommended. Also, traction of the neck was found to be efficient (43). Active motion and pain medication is the standard treatment immediately following a whiplash injury today; although evidence is limited of the efficacy of these treatments (44-46).

The mechanisms of injury have long been a question of controversy as visualisation of injuries by x-ray or MRI has not been possible. However, research has improved and studies on cadavers and volunteers have shown

that whiplash injuries can involve damage to zygopophysial joints, muscles, vertebral arteries, spinal ligaments, discs, and nerve root ganglia (47).

## Pathophysiology and biomechanics

*Traumatic brain injury*

The brain is very soft tissue, well protected by the complex structure of the skull. This complexity has made studies of biomechanical thresholds for TBI difficult (48). It appears that injury more often occurs in cortical/subcortical structures than in the brainstem. Rotation has been shown to produce worse injuries than linear impacts and the minimum acceleration to create a concussion is believed to be about 80-100g, which may occur in a 40km/h car crash (49). According to a recent review, there is, however, no consensus in this matter (48).

Following TBI, focal injuries (haematomas at various locations) or diffuse injuries (diffuse axonal injury (DAI), diffuse brain oedema and hypoxic ischemia) are sometimes detected (50). Temporary neuron dysfunction without actual tissue damage is, however, the most common feature, at least after mild TBI (MTBI) (49). The dysfunction includes a cascade of metabolic changes, for example ion shifts, affected neurotransmission, altered metabolism, and diminished central blood flow (49,51,52). After most MTBI, these changes are temporary and normal function will be restored within days (49). Attempts have been made to find biomarkers for adverse outcome, for example S-100B (53). However, the clinical value of such tests have been questioned due to poor specificity (51). DAI is a rupture of axons that occur immediately or within hours to days after TBI, often including rotation of the head (50). It can be detected on MRI but often not on CT (54). DAI is more common in young people than the elderly and is found in approximately 50% of severe TBI. Severe DAI is a major contributor of bad outcome (50). In the acute phase, another feared complication is macroscopic bleeding that, depending on the severity of the TBI, occurs from about 5% of MTBI patients to nearly 50% in those with severe TBI (55,56). However, only about 3% of all TBI cases require neurosurgery (57).

*Whiplash injury*

It was previously believed that hyperextension of the neck caused injury following whiplash trauma (58). Recent studies show that neck movement during whiplash trauma is very complex. During different phases of the movement, tension, shear, flexion, extension, and compression cause various forces at different levels in the spine (59). Immediately after a rear end impact, the neck forms an S-shaped curve with flexion in the upper cervical spine and extension in the lower cervical spine and then a C-shape follows. Both the upper and lower cervical spine is at risk for extension injury, but seldom flexion injury, in a rear end crash (60).

In the zygopophysial joints, swelling, derangement of collagen, and alteration in nerve signalling can occur after whiplash injury (47). In a study by Lord et al., pain from these joints at C2-C3-level was found in 50% of patients with chronic headache after whiplash injury (61). Damage to the anterior ligaments, dorsal root ganglion, and vertebral arteries have also been shown in different experiments; the clinical importance is unclear (47). Muscle injury measured with creatinine kinase has not been found in chronic whiplash associated disorders (WAD) (62), but other results indicate that biochemical alterations exist, thus, indicating that peripheral nociceptive processes are activated in the trapezius muscle of cases of chronic WAD (63). Disturbed pain modulation and sensitisation probably also play a role in the development of chronic WAD (64). In a recent study, elevated levels of [11C]2D-Deprenyl, a marker for inflammation, were found around the C2 spineosus process in patients with chronic pain after whiplash injury, thus suggesting long-term peripheral inflammation (65). Unfortunately, imaging rarely finds pathology in whiplash patients; the need for objective measures of whiplash injuries is not met (66).

## Epidemiology

### *Traumatic brain injury*

TBI is a contributing factor in about 30% of all injury related deaths (67) and is one of the most common causes of death in young persons (68). If the European (15/100,000/year) (69) and American (17/100,000/year) (67) incidences of death following TBI would be extrapolated to the whole world with its' over 7,000,000,000 inhabitants (70), this would mean that about 1.1 million people are killed by TBI every year. "The silent epidemic" is an appropriate description of the magnitude of the problem (71).

Based on samples of emergency department (ED) visits, samples of hospital discharges and causes of death registers; the incidence of TBI in the USA between 2002 and 2006 was estimated to be 579 per 100,000 inhabitants per year. The ED-visits represented 468/100,000/year and hospitalizations 94/100,000/year (67). In a systematic review of European brain injury epidemiology, incidences were found to vary between 91/100,000/year and 546/100,000/year in different studies (69). In addition, about 30-40% of people who sustain an MTBI do not seek medical care (72,73).

In different studies, the share of mild TBI (MTBI) is 70-90% (74). The true figure is probably over 90% when accounting for persons not admitted to inpatient care or not seeking medical attention (57,72).

The major causes of MTBI are traffic crashes and falls but in young people, sporting mishaps also cause a substantial number of injuries (74). Alcohol inebriation is found in 25-50% of cases (53,75) and men are considered to be at higher risk than women to sustain an MTBI (74).

*Whiplash injury*

The incidence of whiplash injuries can be calculated from different data. In Sweden, during the first part of the past decade, the annual number of insurance claims was about 30,000/year, which corresponds to a national incidence of 330/100,000/year (46). A similar calculation in the UK in 2008 gives an incidence of over 700/100,000/year (76). When looking at ED-visits, the annual incidence of traffic-related whiplash injuries in the United States was 328/100,000/year in 2000 (77). In Umeå, previous studies have found incidences of traffic-related whiplash injuries to vary between 81/100,000/year and 320/100,000/year (78-81). Holm et al. concluded in a review, that the incidence of traffic-related whiplash injuries is at least 300/100,000/year (82).

Most of whiplash injuries are of WAD-grade 1-2 whereas only a few percent are classified as WAD-grade 3 (46). WAD-grade 4 (neck fractures or dislocations) is most often not included in studies of whiplash injuries (83). The incidence of WAD-grade 0 was about 100/100,000/year in Umeå in 1997-98 (81).

Whiplash injuries are mainly caused by traffic crashes although other types of trauma can cause the same acceleration-deceleration mechanism in the cervical spine (14). Björnstig et al. found traffic to cause 69% of soft tissue injuries to the neck and Versteegen et al. found 50% of neck sprains to be traffic-related (78,84,85).

There is a lack of evidence regarding the difference in risk of sustaining a whiplash injury in women and men; however, females are probably at higher risk (82). Kinematic studies have shown that higher acceleration occurs in females compared with males in similar crashes and that several other head-neck motion responses also differ (86,87). As in the case of TBI, young persons have higher incidence figures of whiplash injuries than older persons (82).

## Long-term consequences of mild traumatic brain injury

The body of literature on consequences following TBI is very large. Because the follow-up of TBI in this thesis only includes MTBI, this chapter mainly addresses MTBI. The subdivision of MTBI as a separate entity is widely accepted within the research field and can be illustrated by the fact that in 1997, the WHO Collaborating Centre for Neurotrauma assembled a task force to address MTBI specifically (88).

*Post-concussion symptoms*

Patients' symptoms following MTBI are often divided into three subgroups: physical, cognitive (neuropsychological) or behavioural/emotional (11). Symptoms and cognitive deficits are common immediately after MTBI but often resolve within 3-12 months (89). Several meta-analyses confirm that

cognitive deficits most often resolve within three months after MTBI (90,91). There can, however, still be subgroups of patients with longer-lasting cognitive problems (92,93).

For a significant minority of the patients, symptoms remain for long periods of time. The most common symptoms are headache followed by fatigue, dizziness, poor memory, poor concentration, irritability, and sleep disturbance (57,94-101). The prevalence of symptoms being reported varies between 12 and 63% (57,94,96-103). In a large Swedish multicentre study of self-reported symptoms (physical, cognitive, or emotional), 46% of subjects reported any remaining symptom and 24% reported three or more persisting symptoms three months after MTBI (95).

There are, however, uncertainties about the specificity of self-reported symptoms like these. For example, some studies report no difference in symptoms reported from MTBI patients and control groups (104,105). In addition, previous studies have also found that post-concussion symptoms are frequent in settings of pain-patients (106-108). Fayol et al., in a review, stated that post-concussion symptoms are reported in healthy subjects, general trauma patients, psychiatric patients, neurology patients, patients with minor medical issues, and insurance claimants (109).

*Post-concussion syndrome (PCS)*

In a 1961 study of accident neurosis, Miller described persisting post-concussion syndrome (PCS), including headache, dizziness, irritability, failure to concentrate, noise sensitivity, sleeplessness, depression, and anxiety in 93 of 200 patients who had been referred to mediolegal examination (36,110). Since then, the prevalence of PCS has been studied extensively, and is, when measured with the ICD-10, found to vary between about 20 to 55% in MTBI patients three months or longer post-injury (94,96,102,111). PCS is three to six times more common when assessed using the ICD-10 than when DSM-IV criteria are used (15,112).

*Disability*

Disability is measured with various questionnaires and can range from very mild to severe. It is found in less than 10 to 50% of MTBI (53,57,97-100,111,113,114). For example, independence in the home, ability to sustain previous workload, and problems in family life are measured (7,115).

*Quality of Life*

A 2007 review of the literature on quality of life following MTBI was found to be inconclusive (116); however, several studies have found MTBI patients to have poor outcome on various measures of QoL (53,117-121) .

*Sex-differences*

Sex-differences in outcome within the first one to two weeks following MTBI has been addressed in a number of studies; mostly finding women to have more symptoms compared with men (122-124).

Long-term evaluation of sex-specific outcome after MTBI has been conducted up to two years after the injury. Again, females appear to be at higher risk of unfavourable outcome in most studies. The evidence is, however, limited (123,125-128).

Sex has also been included in several studies of general risk factors for persisting symptoms and disabilities following MTBI. Female gender has often been found to be a risk factor (100,101,114,129-133). However, some authors found no differences between women and men (94,96,134-137).

*Prognostic factors*

The severity of TBI is a good predictor of outcome (138,139). The literature on other prognostic factors after MTBI is heterogeneous and of varying quality according to Carroll et al. (89). In a systematic review, they found that compensation seeking behaviour was strongly correlated with bad prognosis. In another systematic review of prospective cohort studies, Willemse-Van Son et al. concluded that risk factors for having disability after TBI, including all severities were: older age, unemployment at time of injury, pre-injury substance abuse, and a high disability rating at time of discharge from rehabilitation. They found evidence regarding GCS and sex to be inconclusive (140). The important role of psychiatric factors was recently illustrated by Ponsford et al., who found premorbid psychiatric factors and post-injury anxiety, but not the presence of MTBI, to predict persisting symptoms three months after MTBI or general trauma (137). Similar results were found by McLean et al. (141). Other studies have also suggested psychological factors, for example depression and coping styles to be strong predictors of poor outcome (94,131,142-144).

A new systematic review from the WHO Collaborating Centre Task Force on MTBI will perhaps help clarify this issue (145).

## Long-term consequences of whiplash injury

*Symptoms*

The most common acute and persisting symptoms after whiplash injury are neck pain, neck stiffness, shoulder pain, and headache (64,146,147). The prevalence of neck pain and stiffness is about 95% within one week after the injury event according to a review by Sterner & Gerdle (64). Neck pain usually decreases over subsequent days or weeks, and the natural course of recovery is reported to restitution of symptoms within three months post-injury, after which the recovery rates level off (148). However, about 50% of the injured persons report neck pain at one-year post-trauma (83). A

significant number of persons also experience other physical symptoms several years after the injury event such as headache, dizziness, noise sensitivity, and fatigue; cognitive symptoms such as forgetfulness and poor concentration; and affective symptoms such as irritability and frustration (146,147,149-153). If symptoms persist, multidisciplinary evaluation is the standard approach for treatment efforts in Sweden (46).

*Disability*
Prevalence of persisting disability affecting work or leisure time has been reported in 25-32% of whiplash injury cases (81,151). About 5% of the patients will suffer from some degree of permanent disability leading to full- or part-time sick leave (46).

*Quality of life*
Chronic WAD is often associated with chronic pain, social functioning problems, and decreased ability to perform previous activities at work and leisure time, which may lead to decreased life satisfaction (152,154,155). There is, however, no standard tool to evaluate quality of life in whiplash patients. Development of a framework is desirable according to a review by Carlesso et al. (155).

*Prognostic factors*
It is unclear why symptoms persist in some patients. Although evidence is limited (156), some prognostic factors for chronic WAD have been suggested. In a meta-analysis, Walton et al. found the following risk factors: no post-secondary education, female gender, history of previous neck pain, baseline neck pain intensity greater than 55/100, presence of neck pain at baseline, presence of headache at baseline, catastrophizing, WAD-grade 2 or 3 and no seat belt in use at time of collision (157). However, both Carroll et al. and Kamper et al. in reviews found results from different studies pointing in different directions (83,148). Some studies have investigated the importance of mediolegal aspects and found that being involved in an ongoing insurance claim involving tort compensation seems to be associated with poorer chances of recovery (158,159).

# Aims

**General aim**
To investigate the epidemiology and long-term consequences in terms of symptoms, disability, and life satisfaction in cases of traumatic brain injuries (TBI) and whiplash injuries from a well-defined population.

**Study I**
To investigate the incidence, causes, and acute complications of all types of TBI treated in a well-defined population and geographical area.

**Study II**
To analyse sex-differences in symptoms, structure of symptoms, disability, and life satisfaction in a hospital-based cohort of mild TBI (MTBI) three years post-injury. Secondary aims were to investigate the frequency of neck, thoracic, and lumbar back pain among the patients and to find risk factors for adverse outcome of disability and life satisfaction.

**Study III**
To perform a thorough examination of the annual incidences of emergency department (ED) visits attributable to road traffic whiplash injuries in the geographic catchment area of Umeå University Hospital during the past decade. Secondary aims were to compare the number of whiplash injuries with statistics on whiplash claims from the Swedish Insurance Federation to determine whether the proportion of claims have increased or decreased since 2003 and to investigate if the proportion of rear-end crashes causing whiplash injuries have decreased during the study period (along with improved whiplash protection systems in cars).

**Study IV**
To describe epidemiological aspects of all neck injuries following whiplash trauma (whiplash injuries of whiplash associated disorders (WAD) grade 1-4) and the consequent sick leave during a 5-year follow-up. Possible risk factors for sick leave and the cost of loss of productivity were also studied.

**Study V**
To study symptoms and disabilities five years after a whiplash injury using questionnaires designed for MTBI. A second aim was to study life satisfaction, and a third aim was to investigate differences between women and men regarding these variables.

# Materials and Methods

### Setting

This work has been conducted at Umeå University Hospital (UUH). UUH is the only hospital in a well-defined geographical area with a 60 km radius serving 137,000 inhabitants in 2001. It is also the only level 1 trauma centre in Northern Sweden. The next nearest hospital is 110 km away. In Umeå there are no other medical facilities treating trauma victims, and during the study period the general practitioner on call (outside ordinary working hours) was located at the emergency department (ED). This implies that the only cases of injury not treated at the ED are minor injuries treated at primary health care centres during daytime.

### The injury database

At the ED of UUH an injury registration procedure is ongoing. It was established in 1985 and includes Umeå city and the surrounding municipalities Vännäs, Vindeln, Bjurholm, Nordmaling, and Robertsfors. In 1993, a control of the inpatient register for external cause of injury (ICD-10) was set up to make sure no inpatients were missed, and in 1998 a monthly control of the registers quality was introduced. In this control, all registered patients during three randomly selected days are compared with all hospital visits for the same period. The proportion of registration misses during these days is usually 5% for traffic injuries and 10% for other injuries.

Upon arrival at the ED, patients are asked to fill out an injury survey form (**Appendix 1**) with questions of the circumstances of the injury event. If a patient cannot fill out the form, relatives, friends or sometimes ambulance personnel may assist. These forms are compiled by trained coders into a data-file containing all injury events that year, approximately 10,000 cases. In this procedure, the patients' medical records, ambulance reports, and sometimes police reports are scrutinised. The coders occasionally contact the patients by telephone for additional information. All patients are given a unique ID-number. The files are kept at internal servers at the hospital. Patients' social security numbers are removed before researchers can access the section of the file that they need for their analysis.

The data-file contains about 70 items: the patients' sex, age, site of residence, place, time, and date of the injury; up to three diagnosis, maximum AIS, free text describing the injury event, and several data specifics of the injury event, for example, if seat belts and head rests were used.

**Study I**

The study was based on cases from 2001 of traumatic brain injuries (TBI) from the injury database. Inclusion criteria were:

- Injury event within the primary catchment area of UUH.
- Arrival at the ED within 24 h after the injury event.
- Presence of TBI defined as a brain trauma causing any degree of disturbed consciousness (e.g., loss of consciousness (LOC) or disorientation), post-traumatic amnesia (PTA), neurological deficit, severe headache, nausea or vomiting.

All data were re-evaluated, i.e. medical records read to control that no errors were present in the file and to complete the file with information of Glasgow coma scale (GCS), LOC, PTA, results of X-ray, and presence of alcohol inebriation based on the attending physician's judgment, or on occasion blood samples. The data were analysed and presented in terms of descriptive statistics.

**Study II**

The study was based on the same cases as in study I. Those aged 18-64 at the time of follow-up that had a GCS of 13-15 at the ED were included in a 3-year follow-up. Of these 214 cases of mild TBI (MTBI), 200 received a questionnaire including the RPQ, RHFUQ, and LiSat-11 (see below). Thirty-seven persons did not reply. The 163 responders were analysed with the primary objective to describe differences between women and men. Descriptive epidemiology, chi-2-tests, t-tests, multiple logistic regression, and principal component analysis were used to analyse the data. Comparisons were made between the cases and reference groups regarding the answers to the RPQ and LiSat-11.

*Questionnaires*

- Rivermead Post Concussion Symptoms Questionnaire (RPQ) (8)

The RPQ is a validated self-report questionnaire consisting of 16 symptoms commonly exhibited after MTBI. The patient is asked to rate symptoms that have arisen after the injury event and exhibited during the previous 24 h. The scale spans from 0-4 where 0 means no experience of the symptom and 4 means that the symptom is a severe problem. The answers were dichotomized into 0-1: no symptom experienced or 2-4: symptom experienced. Three questions regarding neck pain, thoracic pain, and lumbar pain were added.

- Rivermead Head Injury Follow Up Questionnaire (RHFUQ) (7)

The RHFUQ can be used to assess outcome after mild to moderate TBI in terms of disability. The ten items cover work, social and domestic activities, and relations with friends and family. The participants are asked to rate

changes in their abilities compared with prior to the injury. The answers range from 0: no change to 4: a very marked change. The RHFUQ was dichotomized into 0: no disability and 1-4: presence of disability.

- LiSat-11 (6)

Life satisfaction was assessed using the LiSat-11. The instrument uses a 6-grade scale ranging from 1: very dissatisfying to 6: very satisfying. Eleven items such as life as a whole, mental health, and physical health were assessed. The LiSat-11 scale was dichotomized into satisfied: 5-6 or dissatisfied: 1-4.

**Study III**

The study was based on cases from 2000-2009 of neck injuries following car crashes collected in the injury database. The inclusion criteria were:

- Injury event within the primary catchment area of UUH.
- Cause of injury: road traffic crash.
- Injury of whiplash associated disorders (WAD) grade 1-3.

Data from the latest national statistics on injury claims (2007-2008) were gathered from the Swedish Insurance Federation (SIF). Previously published SIF-data from 2003 were also used (46). The data were analysed and presented as descriptive statistics and the proportion of whiplash claims was calculated and compared among the years with chi-2-tests.

**Study IV**

The study was based on cases of whiplash trauma from 2001 in the injury database. The inclusion criteria were:

- Injury event within the primary catchment area of UUH.
- Arrival at the ED within 30 days after the injury event.
- Mechanism of injury: whiplash trauma.
- Injury of WAD-grade 1-4.

All data were re-evaluated, and the file was complemented with data on WAD-grades. For those patients aged 18-64 at the time of the injury, 5-year data on sick leave from the compulsory Swedish Social Insurance register were added to the file. This register includes sick leave periods over 14 days, and only sick leave periods due to the injury in question were collected.

Epidemiological aspects were presented in terms of descriptive epidemiology. Univariate statistics and multiple logistic regressions were used to analyse sick leave and the possible baseline and demographic risk factors.

**Study V**

The study was based on a 5-year follow up of 18-64 year-old victims of whiplash trauma that occurred in 2001 (WAD-grade 1-3). Traffic and other

injury events were included. A questionnaire containing the RPQ, RHFUQ, LiSat-11, and VAS (see below) was administered. The answers were analysed with descriptive statistics, chi-2 tests, and t-tests.

*Questionnaires*

- The Visual Analogue Scale (VAS) (160)

The VAS consists of a 100 mm straight line with defined end-points ("no pain" and "worst pain imaginable") on which the patients were asked to mark their experienced pain (results in mm). It was used to rate pain intensity for the previous seven days. The VAS is considered to have a high degree of reliability and validity (161).

# Results

### Study I

In 2001, 449 cases of traumatic brain injury (TBI) were encountered across all ages; thus, giving an incidence of 354/100,000/year; see **Figure 1**. The mean age was 23 and men constituted 55% of the cases. Mild TBI (MTBI) was most common constituting 97% of the cases followed by severe TBI (2%) and moderate TBI (1%). The most common cause of injury was falls (55%) followed by traffic injuries (30%); see **Table I**. Intracranial bleedings (ICB) were discovered in 8% of the cases and ~1% required neurosurgery. The cases with ICB are presented in **Table II**.

**Figure 1**. The incidence of TBI in the Umeå region in 2001

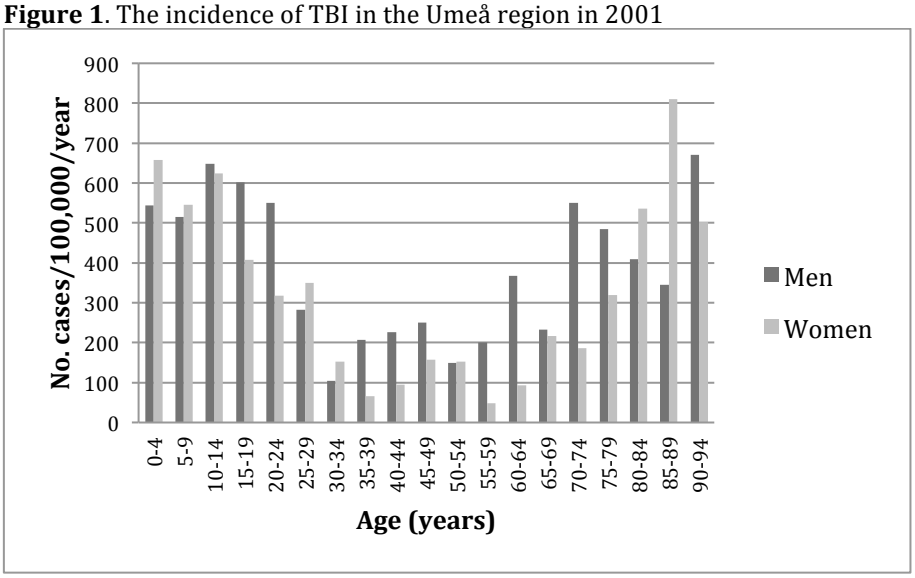



**Table I**. Proportion (%) of types of injury events causing TBI in the Umeå region in 2001

| Age group | Falls | CWO | Traffic crashes |
|---|---|---|---|
| All | 55 | 15 | 30 |
| Children (0-14 years) | 65 | 17 | 18 |
| Adults (15-64 years) | 41 | 17 | 42 |
| Elderly (≥65 years) | 76 | 7 | 17 |

CWO: contact with object

**Table II**. Sex, age, Glasgow coma scale (GCS), type of injury event (I.E.), and type of intracranial bleeding (ICB) in cases of TBI in the Umeå region in 2001 – in order of increasing age

| Sex/age | GCS | Type of I.E. | ICB | Sex/age | GCS | Type of I.E. | ICB |
|---|---|---|---|---|---|---|---|
| F 6 | 15 | CBT | SD/C | M 56 | 15 | B | SD/C |
| F 9 | 15 | CBT | SA/C | M 56 | 15 | B | SD/C |
| F 9 | 13 | CWO | C | M 57 | 15 | CBT | SD/C |
| F 13 | 14 | B | EH | M 61 | 4 | Fall V | SA/C |
| M 19 | 7 | CBT | C | M 66 | 15 | Fall H | SA |
| M 21 | 15 | CBT | C | F 69 | 15 | Fall H | SD |
| M 21 | 10 | CBT | C | M 70 | 15 | MMS | SD/C |
| M 22 | 15 | B | EH/C/SD | M 71 | 15 | Fall V | SD |
| F 24 | 12 | CBT | SD | M 71 | 15 | Fall H | C |
| M24 | 3 | B | EH/C | F 73 | 15 | Fall V | SD |
| F 25 | 14 | B | EH/SD/SA/C | M 73 | 14 | Ped-Veh | SA |
| M 29 | 14 | CBT | EH/C | M 76 | 15 | Fall H | C |
| M 37 | 6 | Ped-Veh | SD/C | M 81 | 14 | Ped-Veh | SA |
| M 39 | 15 | Fall H | C | F 85 | 14 | Fall H | SD |
| M 40 | 3 | Fall V | EH | M 88 | 15 | Fall H | EH/SD |
| F 45 | 15 | Fall H | SA/C | M 89 | 8 | Fall H | SD/C |
| F 50 | 15 | CBT | SD | F 91 | 14 | Fall V | SD/SA/C |

F: female. M: male. CBT: car, bus, or truck crash. CWO: contact with object. B: bicycle crash. Ped-Veh: pedestrian hit by vehicle. Fall H (horizontal): fall on the same level. Fall V (vertical): fall from one level to a lower level. MMS: motorcycle, moped or snowmobile crash. SA: subarachnoidal haemorrhage. C: contusion. EH: epidural haematoma. SD: subdural haematoma.

### Study II

In the 3-year follow-up of the 163 cases of MTBI, women had worse outcome in terms of symptoms and disability, but not regarding life satisfaction. Post-concussion syndrome (PCS) was found in 50% of the women and 30% of the men. Back pain was found in 62% of the women and 37% of the men. Any degree of disability was found in 52% of the women and 37% of the men, and 57% of the women compared with 56% of the men were satisfied with their lives as a whole. The MTBI cases had significantly more symptoms and lower life satisfaction than the references; see **Table III** and **Figure 2**. The principal component analysis found three components in women and two in men; apart from this, the structure of symptoms on the RPQ was similar.

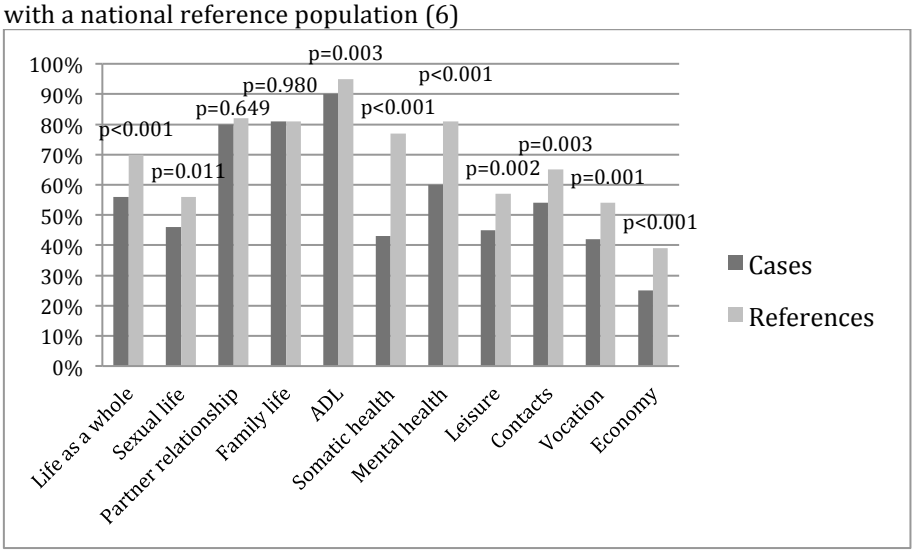
In the logistic regressions, the strongest risk factor for having a life satisfaction below median was to live alone. In women, being injured in traffic was also a risk factor while in men, a high first RPQ-component score (RPQ-CS) and being younger than 40 were significant risk factors. Risk factors for disability in women were a high first RPQ-CS and having sustained an additional TBI after 2001, while in men, a high first RPQ-CS and high back pain were risk factors for disability.

**Table III**. Proportion of women and men aged 18-64 exhibiting symptoms three years after MTBI in the Umeå region in 2001 in comparison with references aged 18-64 (blood donors; Nilsson Sojka & Sojka, unpublished data)

| | **Present study*** | | | **References*** | | |
|---|---|---|---|---|---|---|
| | **Women** | **Men** | | **Women** | **Men** | |
| **Somatic symptoms** | **%** | **%** | *p-value* | **%** | **%** | *p-value* |
| Headache | 56 | 36 | ***0.011*** | 7 | 4 | *0.249* |
| Dizziness | 35 | 19 | ***0.019*** | 8 | 2 | ***0.002*** |
| Nausea, vomiting | 16 | 6 | ***0.042*** | 0 | 0.7 | *0.524* |
| Fatigue | 47 | 30 | ***0.022*** | 28 | 18 | ***0.017*** |
| **Cognitive symptoms** | | | | | | |
| Thinking slow | 25 | 14 | *0.066* | 2 | 3 | *0.319* |
| Poor memory | 34 | 27 | *0.376* | 7 | 6 | *0.494* |
| Poor concentration | 35 | 25 | *0.166* | 6 | 5 | *0.902* |
| **Vision-related symptoms** | | | | | | |
| Double vision | 3 | 5 | *0.701* | 0 | 0.4 | *1.000* |
| Blurred vision | 21 | 14 | *0.242* | 3 | 4 | *0.417* |
| Sensitivity to light | 25 | 19 | *0.353* | 6 | 3 | *0.082* |
| Noise sensitivity | 31 | 17 | ***0.035*** | 7 | 3 | ***0.047*** |
| **Affective symptoms** | | | | | | |
| Feeling depressed | 41 | 22 | ***0.009*** | 5 | 4 | *0.618* |
| Feeling frustrated | 34 | 24 | *0.179* | 8 | 3 | ***0.015*** |
| Restlessness | 27 | 15 | *0.063* | 3 | 3 | *0.808* |
| Irritability | 31 | 24 | *0.344* | 5 | 3 | *0.146* |
| Sleep disturbance | 37 | 25 | *0.114* | 10 | 10 | *0.965* |

Significant p-values are highlighted in bold.
The symptoms are structured as suggested by Lundin et al. (111)
*Present study vs. references: Significant differences on all items except double vision in women.

**Figure 2**. Proportion of MTBI patients aged 18-64 from the Umeå region in 2001, being satisfied or very satisfied with various aspects of life compared with a national reference population (6)




ADL: activities of daily living

**Study III**

During the 10-year period 2000-2009, 3,297 cases of soft tissue neck injuries (whiplash injuries of whiplash associated disorders (WAD) grade 1-3) for all ages, were collected in the injury database. The incidence was 235/100,000/year, see **Figure 3**. The sex-distribution was quite equal with 52% being women. The most common injury age group was 20-24; see **Table IV**. Car occupants comprised 86% of the cases followed by bicycle riders (6%). The average yearly increase in incidence was 1%. The share of patients reporting their injuries to the insurance companies decreased significantly ($p<0.001$) between 2003 and 2007/2008. The proportion of rear-end crashes decreased from 55 to 45% from 2000-2009.

**Figure 3**. The incidence of whiplash injuries (WAD-grade 1-3) in the Umeå region following traffic incidents

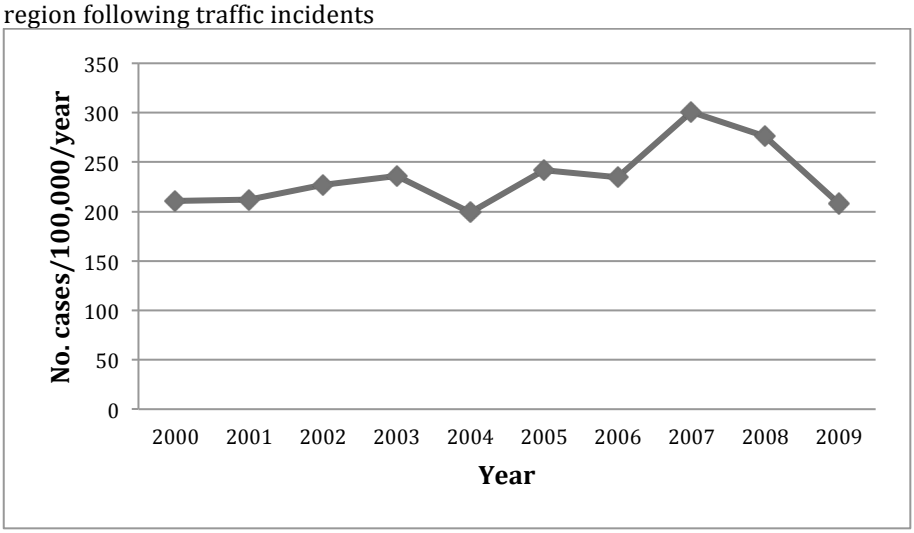



**Table IV**. The incidence of whiplash injuries (WAD-grade 1-3) in different age groups in the Umeå region following traffic incidents during 2000-2009

| Age Group (years) | No. cases/ 100,000/year | Age Group (years) | No. cases/ 100,000/year |
|---|---|---|---|
| 0-4 | 4 | 45-49 | 307 |
| 5-9 | 35 | 50-54 | 215 |
| 10-14 | 73 | 55-59 | 179 |
| 15-19 | 412 | 60-64 | 125 |
| 20-24 | 452 | 65-59 | 53 |
| 25-29 | 404 | 70-74 | 65 |
| 30-34 | 398 | 75-79 | 46 |
| 35-39 | 345 | 80-84 | 21 |
| 40-44 | 303 | 85-89 | 22 |

**Study IV**

The incidence of neck injuries (WAD-grade 1-4) following whiplash trauma from all types of injury events was 383/100,000 in 2001; see **Figure 4**. Sixty-eight percent of the injuries occurred in traffic, 18% were a result of contact with object and 14% was due to falls. Men were slightly overrepresented (56%). In 32% of the cases, the injuries were classified as WAD-grade, 65% had WAD-grade 2-3 and 3% had WAD-grade 4. In 14% of the cases in age group 18-64, sick leave was granted for more than 14 days. The median number of days on sick leave in this group was 298 (mean 637). Three percent of the cases remained on sick leave for the whole 5-year follow-up. No cases of neck injury following falls rendered sick leave of more than 14 days. For information on sick leave in subgroups, **see Table V**. Risk factors for being granted sick leave were WAD-grade 1, being injured in traffic, and being injured at velocity exceeding 50 km/h. The cost of loss of productivity was 96,500 USD per case on sick leave.

**Table V**. Proportion of sick leave ≥15 days being granted and the duration of sick leave among cases aged 18-64 of whiplash injuries (WAD-grade 1-4) in the Umeå region in 2001

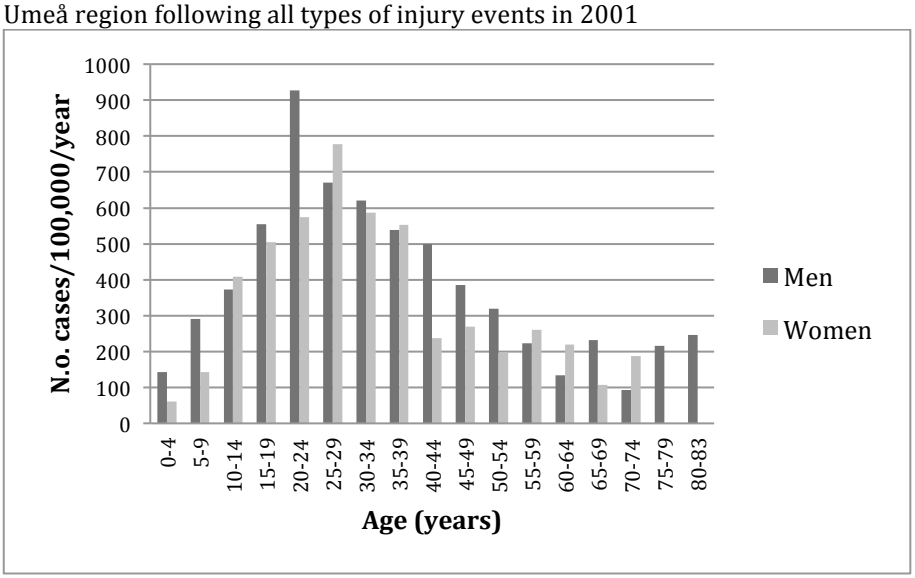
| | **Presence of sick leave** | **Duration (days)** | | | **Presence of sick leave** | **Duration (days)** | |
|---|---|---|---|---|---|---|---|
| | **%** | Mean | 95% CI | | **%** | Mean | 95% CI |
| **Sex** | *p=0.285* | *p=0.575* | | **Causes** | *p=0.001*** | *p=0.906* | |
| Men | 16 | 621 | 391-851 | Falls | 0 | 0 | 0 |
| Women | 12 | 662 | 374-951 | CBT | 17 | 672 | 478-865 |
| **Age** | | | | OVRE | 13 | 428 | -443-1299 |
| **(years)** | *p=0.007** | *p=0.567* | | CWO | 7 | 342 | -400-1085 |
| 18-19 | 0 | 0 | | **WAD** | *p=0.067* | *p=0.914* | |
| 20-24 | 6 | 278 | -211-768 | 1 | 19 | 643 | 389-897 |
| 25-29 | 17 | 694 | 293-1096 | 2-3 | 11 | 623 | 359-886 |
| 30-34 | 18 | 754 | 193-1316 | 4 | 22 | 752 | -7793-9296 |
| 35-39 | 16 | 525 | -81-1131 | **Add. in** | *p=0.589* | *p=0.648* | |
| 40-44 | 9 | 1091 | -1086-3268 | None | 14 | 677 | 461-892 |
| 45-49 | 21 | 643 | -185-1472 | AIS 1 | 15 | 464 | 118-809 |
| 50-54 | 33 | 409 | 86-731 | AIS 2 | 13 | 505 | -1361-2371 |
| 55-59 | 14 | 1350 | 417-2283 | AIS 3 | 50 | 1424 | 0 |
| 60-64 | 18 | 153 | -991-1297 | AIS 4 | 0 | 0 | 0 |

*Post-hoc tests revealed the following results: In the partitioning of $G^2$-test 18-24 year-olds were less prone to be granted sick leave than 25-29 year-olds. When doing pairwise comparison using Bonferroni correction 18-19 year olds and 20-24 year-olds were less prone to be granted sick leave than 50-54 year-olds.

**In the two post-hoc tests, the number of patients granted sick leave from Falls was significantly lower compared with car, bus or truck crashes.

CBT: car, bus or truck crash. OVRE: other vehicle-related injury events. CWO: contact with object. WAD: whiplash associated disorders. Add. in: additional injuries. AIS: abbreviated injury scale.

**Figure 4**. The incidence of whiplash injuries (WAD-grade 1-4) by age in the Umeå region following all types of injury events in 2001




**Study V**

Five years after having sustained a whiplash injury the 18-64 year-old responders had significantly higher frequencies of all symptoms reported in comparison with a reference population; see **Table VI**. Three or more RPQ-symptoms were found in 54% of the women and 50% of the men, and back pain was encountered in 57% of the women and 59% of the men. The most frequently reported disabilities on the RHFUQ were difficulty sustaining previous workload (44%), being tired at work (43%), and having an affected ability to enjoy previous leisure activities (34%). Women had significantly higher pain intensity than men on the VAS (36 vs. 23 mm). Apart from this, there were no significant sex-differences on any of the instruments. Life satisfaction was lower in the follow-up group than in the reference population, see **Figure 5**.

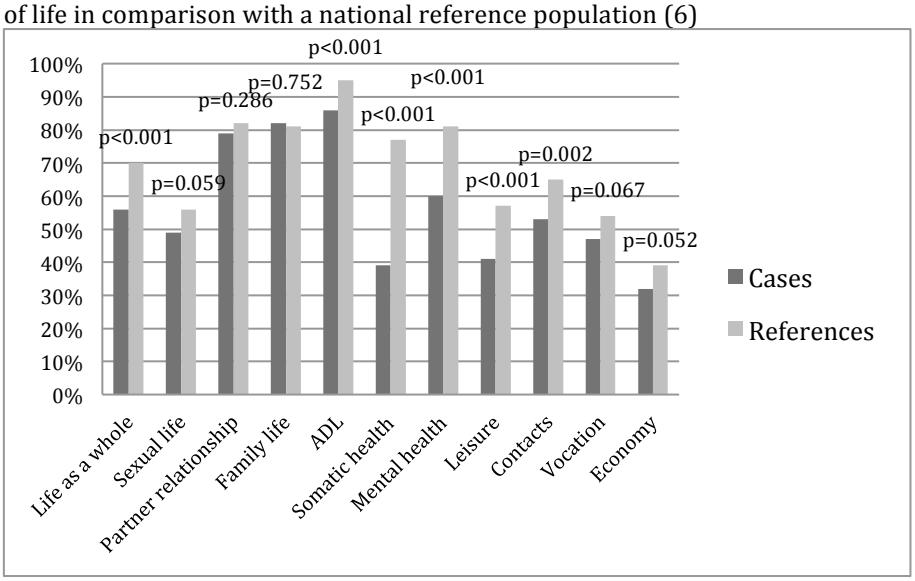
A comparison, between the whiplash-cases of study V and the cases of MTBI described in study II was conducted with respect to RPQ-symptoms with the addition of back pain; see **Table VII**. The only differences between these groups were that women with MTBI had significantly or close to significantly higher frequencies of headache, dizziness, feelings of depression, and frustration compared with women with whiplash injuries. Men with whiplash injuries had more cervical and thoracic back pain along with restlessness and slow thinking compared to men with MTBI.

**Table VI**. Proportion of 18-64 year-olds exhibiting symptoms five years post whiplash injury (WAD-grade 1-3) in the Umeå region in 2001 compared to age-matched references (blood donors; Nilsson Sojka & Sojka, unpublished data)

| | **Present study** | **References** | |
|---|---|---|---|
| **Somatic symptoms** | **%** | **%** | *p-value* |
| Headache | 37 | 6 | ***<0.001*** |
| Dizziness | 20 | 4 | ***<0.001*** |
| Nausea, vomiting | 10 | 0.5 | ***<0.001*** |
| Fatigue | 41 | 23 | ***<0.001*** |
| **Cognitive symptoms** | | | |
| Thinking slow | 27 | 3 | ***<0.001*** |
| Poor memory | 39 | 6 | ***<0.001*** |
| Poor concentration | 32 | 6 | ***<0.001*** |
| **Vision-related symptoms** | | | |
| Double vision | 7 | 0.5 | ***<0.001*** |
| Blurred vision | 22 | 3 | ***<0.001*** |
| Sensitivity to light | 29 | 5 | ***<0.001*** |
| Noise sensitivity | 32 | 5 | ***<0.001*** |
| **Affective symptoms** | | | |
| Feeling depressed | 21 | 4 | ***<0.001*** |
| Feeling frustrated | 25 | 6 | ***<0.001*** |
| Restlessness | 25 | 3 | ***<0.001*** |
| Irritability | 32 | 4 | ***<0.001*** |
| Sleep disturbance | 30 | 10 | ***<0.001*** |

Significant p-values are highlighted in bold.
The symptoms are structured as suggested by Lundin et al. (111)

**Figure 5**. Proportion of 18-64 year-old whiplash-cases (WAD-grade 1-3), from the Umeå region in 2001, being satisfied or very satisfied with various aspects of life in comparison with a national reference population (6)




ADL: activities of daily living

**Table VII**. Comparison of the frequency of RPQ-symptoms with the addition of back pain between cases of MTBI and cases of whiplash injuries (WAD-grade 1-3) in the Umeå region in 2001

| | **Women** | | | **Men** | | |
|---|---|---|---|---|---|---|
| | MTBI | Whiplash | | MTBI | Whiplash | |
| **Somatic symptoms** | % | % | *p-value* | % | % | *p-value* |
| Headache | 56 | 41 | *0.064* | 36 | 31 | *0.494* |
| Dizziness | 35 | 21 | ***0.036*** | 19 | 19 | *0.986* |
| Nausea, vomiting | 16 | 14 | *0.759* | 6 | 6 | *0.920* |
| Fatigue | 47 | 41 | *0.458* | 30 | 40 | *0.123* |
| **Cognitive symptoms** | | | | | | |
| Thinking slow | 25 | 26 | *0.911* | 14 | 27 | ***0.023*** |
| Poor memory | 34 | 39 | *0.483* | 27 | 36 | *0.229* |
| Poor concentration | 35 | 33 | *0.758* | 25 | 31 | *0.397* |
| **Vision-related symptoms** | | | | | | |
| Double vision | 3 | 5 | *0.701* | 5 | 8 | *0.412* |
| Blurred vision | 21 | 24 | *0.636* | 14 | 17 | *0.578* |
| Sensitivity to light | 25 | 31 | *0.406* | 19 | 26 | *0.246* |
| Noise sensitivity | 31 | 38 | *0.336* | 17 | 25 | *0.179* |
| **Affective symptoms** | | | | | | |
| Feeling depressed | 41 | 22 | ***0.007*** | 22 | 20 | *0.761* |
| Feeling frustrated | 34 | 21 | *0.057* | 24 | 30 | *0.403* |
| Restlessness | 27 | 21 | *0.380* | 15 | 31 | ***0.009*** |
| Irritability | 31 | 34 | *0.672* | 24 | 29 | *0.508* |
| Sleep disturbance | 37 | 30 | *0.355* | 25 | 31 | *0.397* |
| **Back Pain** | | | | | | |
| Cervical | 47 | 46 | *0.977* | 31 | 49 | ***0.012*** |
| Thoracic | 32 | 40 | *0.336* | 18 | 39 | ***0.003*** |
| Lumbar | 39 | 40 | *0.884* | 21 | 31 | *0.180* |

Significant p-values are highlighted in bold.
The symptoms are structured as suggested by Lundin et al. (111)

# Discussion

The incidences of both traumatic brain injuries (TBI) (354/100,000/year) and whiplash injuries (383/100,000/year) found in this thesis are high. For comparison, the incidences of prostate cancer and hip fractures are about 200/100,000/year each, in Sweden (162,163). It seems justified to denominate TBI and whiplash injuries as important health problems. At the emergency department (ED) of Umeå University Hospital (UUH), these injuries, alone or concomitant with other injuries, comprise about 10% of the injury panorama. Immediately after the injury event, especially the cases of TBI demand resources, because a CT-scan or admission for inpatient observation is usually needed. For example, in 1998 the cost for a typical inpatient observation period after MTBI was 556 USD and the cost for a CT-scan was 232 USD (164). Whiplash injuries are less costly and demands fewer resources than TBI, because inpatient observation is seldom required (78,165). The long-term consequences for some of the patients in both groups are, however, life changing with physical, psychological, and social factors contributing (166). The costs to society for health care, but foremost, for the loss of productivity because of long-term sick leave is very high (57,165).

In the following sections, the results on TBI and whiplash injuries are separately discussed in comparison with the pre-existing literature. The importance of psychological factors is discussed even though that expands the discussion beyond the results of this thesis. However, such factors are very important to recognise both for TBI and whiplash injuries. Suggestions for areas suitable for preventive work along with clinical recommendations are given. Finally strengths and weaknesses are addressed.

## Key findings

*Findings corresponding to the main aims*

The main aims of this study were to investigate the epidemiology of TBI and whiplash injuries as well as the long-term consequences in terms of symptoms, disability, and life satisfaction following these injuries. The findings show that the incidence of TBI treated at the ED of UUH was 354/100,000/year in 2001. The incidence was highest among children, young adults, and elderly persons. Among adults with mild TBI (MTBI), about 50% of the injured women and 30% of the injured men fulfilled the ICD-10 criteria of post-concussion syndrome (PCS) (5), and the same proportion of subjects had some degree of disability three years after the injury event. The rate of symptoms exhibited by the study cases was higher than among healthy references and life satisfaction was lower compared to a Swedish reference population (6). The incidence of whiplash injuries

following all types of injury events was 383/100,000/year. Following traffic incidents, the incidence was relatively stable during 2000-2009, at a mean of 235/100,000/year. In the follow-up of the 2001's cases, the results showed that about 50% of both adult women and men reported three or more symptoms and some degree of disability five years after the injury. As in the cases of MTBI, the cases of whiplash injuries had higher rates of symptoms and lower life satisfaction in comparison with the reference populations.

*Other interesting findings*

Apart from the findings corresponding with the main aims, several other interesting findings are highlighted in the thesis. Regarding MTBI, it is of clinical interest to note that intracranial bleedings (ICB) occurred in 16% of the elderly persons, but only in 3% of the children and 5% of the adults. Elderly persons often sustained ICB following low-energy trauma. Also of interest, for trauma physicians, is the patient who had no history of loss of consciousness (LOC) at the scene of the bicycle crash, but who later deteriorated at the ED because of an epidural haematoma. The case illustrates that LOC is an unreliable predictor of ICB and that evaluating the level of impact energy is important. In addition, half of those with ICB had a GCS of 15 when first assessed at the ED.

In the 3-year follow-up of MTBI the results showed that women had more symptoms and disability than men and the structure of symptoms reported by women and men were different; thus, suggesting that women and men should be studied separately. Moreover, the consequences of a high degree of post-concussion symptoms were shown: it leads to high disability rates in women and men, and low life satisfaction, at least in men. However, in both women and men, the strongest risk factor for a life satisfaction below median was to live alone.

Five years after whiplash injuries no difference in symptoms or disabilities was found when comparing women and men except that women reported higher pain intensity. Long-term sick leave was granted in 14% of the cases of whiplash injuries and the cost of loss of productivity during the 5-year follow-up was 96,500 USD per person on sick leave ≥15 days. A connection between the type of injury event and presence of sick leave was shown: car crashes, to higher extent than falls, led to the granting of sick leave. The presence of a neck fracture was not associated with longer sick-leave periods than WAD 1-3-injuries.

Finally the comparison of RPQ-symptoms with the addition of back pain only showed minor discrepancies between cases of MTBI and cases of whiplash injuries. This implies that symptoms after these injuries may be overlapping and that it is important to evaluate a wider range of symptoms than only neck pain when evaluating cases of whiplash injuries because

treatment and rehabilitation of these symptoms may promote recovery and improved life satisfaction.

## Traumatic brain injury

*Epidemiology*

The incidence of TBI is well within the span of previous reviews (67,69,74), and corresponds well to a recent large German study that found an incidence of TBI (all ages) of 332/100,000/year (57). Typically, children, adolescents, and elderly persons have the highest incidences (74,167-169). This thesis confirms that pattern. The results suggest that children and adolescents are at risk because of sports activities and play; young adults are, in addition, often present in environments in which alcohol and violence play a role. The 30% of cases injured in vehicle related events were often adults. Young adult drivers are at high risk because of their risk-taking behaviour and lack of experience in traffic compared with older adults (170).

Elderly persons fall more easily than younger persons. Risk factors for falls in elderly persons include reduced balance, strength, and coordination (171). Elderly persons are probably also less successful in protecting their heads because these same factors. Moreover, elderly persons are considered more vulnerable than younger persons and more easily sustain subdural bleedings (172). This is reflected in this thesis by the fact that the elderly persons, to higher extent than younger persons, sustained ICBs (often subdural) from low-energy trauma.

Fifty-five percent of the cases of TBI were men. Other studies of TBI and MTBI have often found even higher male percentages (57,74,167,173). Dick et al., however, found female athletes to be at higher risk for concussion than male athletes (174). It is unclear why the proportion of men is lower than usual, in our study. Maybe the increasing equality between men and women regarding work life, sports practice, and transportation has levelled out the previous causes of sex-differences in the incidence of TBI. The largest differences between men and women occur in early adulthood (57,67,79,169). According to Bruns et al., this phenomenon can be explained by the “testosterone years” occurring in males at this point in life (169). This coincides with the period (ages 15-25) when driving mopeds, motorcycles, and snowmobiles is introduced, and the results show that men are heavily overrepresented in crashes with those types of vehicles.

Bicycle injuries are especially common in Umeå because of a young population that traditionally uses bicycles for transportation. In the study of the epidemiology of TBI, bicycle riders accounted for 12% of the injuries. One in every ten injured cyclists have a TBI (175). Helmet legislation for children under the age of 15 was launched in 2005 and it is hoped to reduce TBI in children. Experiences from the use of bicycle helmets in other countries are good (176,177).

**Recommendations for prevention of traumatic brain injury**

According to the results in this thesis, injury preventive measures in young and middle aged adults should include:

- Continuous work on improved traffic safety.
- Efforts to reduce alcohol consumption.
- Measures to reduce TBI in leisure and sports activities, especially in horse riding, football/soccer, and ice hockey.

In young children and elderly persons the most important field of prevention would be:

- Fall-prevention

*Symptoms*

Three years after MTBI, about 50% of the women and 30% of the men in the 18-65 age group met the ICD-10-criteria for PCS. This is at the top of the span of previous literature (94,96,102,111). At the population-level, this illustrates the magnitude of the problem with sequelae following MTBI. At the individual level, the single symptoms are, however, what bother the patients. As previously mentioned, the most common symptoms according to previous literature, also found in this study are headache and fatigue (57,94-101). Headache is related to impaired quality of life (QoL), disability, productivity loss, and high health care consumption (178). Fatigue is related to poor general health and psychological morbidity although the causalities of those relationships are unclear (179,180). At least headache is a condition in which various possible treatments exist, and the patients should be offered such efforts. There is, however, currently a lack of guidelines for specific treatment of post-traumatic headache (181).

Cognitive deficits such as poor memory, slow thought, and concentration problems are not quite as common as headache and fatigue (95) but were still found in ~30% of the cases of this study. Despite meta-analyses having shown cognitive difficulties not to persist after MTBI (90,91), such deficits still cause substantial difficulties for some patients. It is important to identify subjects with cognitive deficits because neuropsychological testing might detect impairments and cognitive rehabilitation may lead to improved function; thus, making coping easier, for example, work demands (182).

Forty-one percent of the women and 22% of the men stated on the RPQ that they had feelings of depression. In a previous study on the same cohort (166) 25% of the patients reported mild to moderate depression and 15% reported moderate to severe depression on the Beck Depression Inventory-II (BDI-II) (2). In the literature, depression after TBI has been found in 10 to 77% of cases (183). Further, previous studies have shown that depression is associated with more symptoms and prolonged recovery in cases of MTBI (94,144,183,184). MTBI is also considered to be a risk factor for depression (36,185). This indicates that identifying and treating depression after MTBI is very important.

*Disability and life satisfaction*

A high first RPQ-component score, i.e., a high number of symptoms, was a risk factor for disability in men and women. The connection between symptoms and disability has been shown by several authors (100,111,186). There was also a connection between RPQ-symptoms and life satisfaction, although only significant in men. A similar result for men and women combined has been shown by King et al. (187). Moreover, life satisfaction in both women and men was lower compared with the references. This is also in accordance with previous literature (53,116-121,128,188). In women, a high first RPQ-component score did not reach significance as a risk factor for low life satisfaction. This might be because of a type two error but it could also mean that RPQ-symptoms affect life satisfaction more in men than in women. In both women and men, living alone was the strongest risk factor for low life satisfaction. It is a well-known fact that marriage correlates with good health (189). Marriage also appears to strengthen global happiness and satisfaction in women more than in men (190). Maybe soft factors, such as marriage, have a higher impact than physical symptoms on life satisfaction in women. The results from this thesis support that suggestion; showing that women had more symptoms and disability than men but not lower life satisfaction. On the other hand, some symptoms were significantly more frequent among women than among men in the reference population as well. This can be explained in two ways, women may have more symptoms than men or women may report symptoms differently than men. The latter has been suggested to bias the research of TBI and gender (191).

**Whiplash injury**

*Epidemiology*

Also, the incidence of whiplash injuries treated at the ED seems to be comparable with incidences found in previous reviews (64,82). Since the 1980s, there has been an increase in incidence of traffic-related whiplash injuries; see **Table VIII** referencing previous studies from the primary catchment area of UUH. There are several possible explanations discussed in more detail in study III: The propensity to attend the ED following whiplash injuries may have increased, the data-collection may have improved, or the injuries may, in fact, have increased. Another possibility is that the ongoing conversion of conventional intersections with stop sign or traffic signal control, to modern roundabouts, has allowed an increase in traffic density (192) without an increase in crashes (193,194). That could partly explain why the incidences seem to have levelled since the late 1990s.

**Table VIII.** The incidence of whiplash injuries following traffic incidents among adolescents and adults in the Umeå region in 1985-2009. Summary of available studies.

| Year | Incidence | Authors | Inclusion criteria |
|---|---|---|---|
| 1985-86 | 114/100,000/year | Björnstig et al. (78) | Traffic incidents, ages 10-59, soft tissue injuries, ED |
| 1988-90 | 217/100,000/year | Bring et al. (79) | Traffic incidents, ages 15-65, neck injuries AIS <3, ED |
| 1990-91 | 147/100,000/year | Bylund et al. (80) | Car crashes, ages 16-65, cervical strains, ED, only Umeå city |
| 1997-98 | 320/100,000/year | Sterner et al. (81) | Car or bus-crash, ages 16-64, WAD 1-3, ED and GP:s |
| 2000-09 | 325/100,000/year | Styrke et al. (present study) | Traffic incidents, ages 15-64, WAD 1-3, ED |

The authors, based on figures from the original articles, the original data-files and population statistics from Statistics Sweden, recalculated the incidences.

In the 1-year study of the incidence of whiplash injuries following all types of injury events, traffic crashes caused 61% of the injuries. This means that 39% of the cases were caused by non-traffic incidents, a figure higher than the 20% found in a previous study from Umeå by Bring et al. (79). The foremost cause of injury, other than the 61% traffic incidents, was contact with object (18%) followed by falls (14%), and other vehicle related injury events (7%). The non-traffic cases are not extensively studied, but are important for the clinician to be aware of. The mechanisms of trauma may be similar to that of car crashes in the aspect that the head may pivot above the shoulder region, without hitting an object or the ground. Neck fractures are also known to sometimes spring from falls, especially in elderly people (195,196). Apart from Bring et al., a few other previous studies have looked at whiplash injuries following all types of trauma. Versteegen et al. found the most common causes of neck sprains, not arising from car crashes, to be falls (25%), sporting incidents (24%), and bicycle crashes (14%) (85) whereas Björnstig et al. found that falls caused 56% of non-traffic whiplash injuries (78).

In the 10-year study of whiplash injury incidence following traffic crashes, 52% of the injured patients were women. In the 1-year study including all types of injury events women constituted 44% of the injured persons. A previous study from Umeå, on all types of injury events, showed 46% of the injured to be women (79). Studies, including traffic crashes, sometimes show higher female rates, for example Quinlan et al. and Crouch et al. found women to comprise 60% of ED-visits due to whiplash injuries (77,197). Sterner et al. and Versteegen et al., however, only found 49% to be women in their studies on traffic-cases (81,84). Because Krafft et al. have shown that

women are at higher risk than men to have permanent disability from whiplash injury following rear end impacts (198), and because about 55% of all patients seeking care following car crashes in Umeå are women (194), I would have anticipated a higher frequency of female injuries. This probably illustrates that whiplash injuries and chronic whiplash associated disorders (WAD) may have different gender-patterns in various settings because of, for example, different traffic structure and care-seeking behaviour.

**Recommendations for prevention of whiplash injury**

According to the results in this thesis, injury preventive measures should include:

- Continuous work on improved traffic safety, especially transformation of traditional intersections to modern roundabouts (199).
- Continuous work on car design to prevent whiplash injuries following all directions of impact.
- Fall-prevention in elderly persons.

*Symptoms*

Fifty-two percent of the persons answering the follow-up questionnaires five years after whiplash injury reported presence of at least three symptoms on the RPQ, and the mean pain intensity on the VAS was 30 mm to be compared with Kyhlbäck et al. who found the mean VAS to be 42 mm one year after whiplash injury, (153). Altogether, this shows that persons injured by whiplash trauma, to a high extent, suffer from persisting symptoms; a conclusion confirmed by previous studies (83,146,147,151,152,200). Also symptoms not so commonly investigated were found, for example, lumbar back pain, cognitive symptoms, and sleep disturbance; the survey extended beyond neck pain, neck stiffness, and headache. That the symptomatology after whiplash injuries is broad, has also recently been highlighted in a population-based health survey from Norway (201).

The rate of self-reported feelings of depression on the RPQ was 22% in women and 20% in men. In a previous study on the same cohort, depression according to BDI-II (2) was found in 20% of the patients (150), the result from the RPQ, therefor, seem valid. In a previous study of depression in a survey of all inhabitants in Nord-Trøndelag, Norway, 15% of people who reported previous whiplash injury also reported depression (202). A meta-analysis of risk factors for chronic WAD has found depression not to influence outcome (157); although several single studies have (150,203-205). In whiplash injured persons, neck pain intensity predicts post-traumatic depression (206,207). There is probably a complex interaction between symptoms, depression, other psychological factors (for example anxiety), and outcome. This has been addressed in a series of studies by Börsbo et al. (204,208-210).

*Disability and life satisfaction*

Any degree of disability measured on the RHFUQ was found in 51% of the women and 54% of the men in the 5-year follow-up of the whiplash injured. This was higher than the ~30% previously reported from our area (81). The same questionnaire was, however, not used and disability, thus, not equally defined. In fact, to my knowledge, no previous study has utilized the RHFUQ on cases of whiplash injuries; future confirmation of the findings is, therefore, desirable.

The fact that so many patients report symptoms and disability after whiplash injuries is alarming, especially because these problems are linked to impaired life satisfaction and quality of life (155). As in the present study, pain intensity has been shown to influence quality of life in whiplash patients (204), and this emphasizes the importance of treatment of pain. Affected life satisfaction or quality of life in whiplash patients has also been shown by several other authors (152,154,205,211). It is worth highlighting that the results of this thesis show that life satisfaction is inferior to that of the reference population not only in aspects like physical and mental health but also activities of daily life and leisure.

The present study shows no sex-differences regarding symptoms, disability, and life satisfaction five years after a whiplash injury. Similar results were found by Peolsson et al. (205).

*Sick leave and the cost of loss of productivity*

No significant differences were found between women and men regarding long-term sick leave following whiplash injuries. There was, however, a non-significant trend that the proportion of men granted sick leave was higher than the proportion of women. Sixteen percent of the men and 12% of the women were granted sick leave for more than 14 days. The women, however, had a higher median number of sick days (also not significant). Our results are supported by Holm et al. who studied sex-differences in work disability following whiplash injuries in an insurance company cohort and found no differences between women and men (212). After five years, 3% of the subjects of the present study were still on 100% sick leave. This is consistent with a previous review of return to work after whiplash injuries that concluded that the rate of return to work was 95% among cases of whiplash injuries (213). One must, however, remember that return to work only mirrors the level of disability to some extent. Holm et al. showed that 67% of whiplash claimants, with at least 10% disability, returned to full-time work capacity (212). When discussing predictors of return to work, recovery expectations have been shown to be important (214). Ozegovic et al. found predictors of low return to work expectations in whiplash patients to be: depressive symptomatology, lower education, lower income, male sex, and greater initial pain (215). Identification of subjects with depression and pain

followed by interventions aiming at those factors might promote return to work.

The cost of loss of productivity was 96,500 USD per person on sick leave, a figure that fairly well corresponds to Radetzkis conclusion that the 1-year cost projected into the future for whiplash injuries in Sweden is 550 million USD (165).

**The crash in relationship with psychological factors**

The present study shows that a significantly higher percentage of whiplash-patients are granted sick leave as a consequence of traffic crashes rather than falls. This can be related to a higher amount of energy involved in a car crash than in a fall, but it is likely also related to some psychological factors such as post-traumatic stress reactions. A car-crash is a frightening event and about 6-25% of the victims develop a post-traumatic stress disorder (PTSD) (216). PTSD is an anxiety disorder following a traumatic event. It features re-experience, avoidance, and hyper-arousal (217). It is associated with depression and pain (217,218) and a link has been shown between PTSD and the development of chronic WAD (219). Even if the criterion of PTSD is not fulfilled, many patients still report some post-traumatic stress reactions. In a previous study on the whiplash-cohort of this thesis, mild to severe stress levels were shown in 37% of the patients (150). Moreover, PTSD frequently co-occurs with MTBI (220) and has been suggested to be a factor in the development of PCS (221). A history of stressful events prior to an MTBI has also been shown to predict bad outcome (143). In a recent study, the prevalence of PTSD after falls was 13% (222).

Following traffic crashes, there is also a litigation issue present. As mentioned previously, the risk of making a claim is higher if the chance of compensation is higher, and symptoms have been shown to prevail after whiplash injuries if a litigation process is ongoing (159). The same connection between litigation and MTBI has been suggested by Carroll et al. in a review (89).

Another aspect of the importance of a traffic crash is the knowledge among people that traffic crashes can cause whiplash injuries and also persisting symptoms after TBI. This phenomenon has been studied comparing western countries with Lithuania. Ferrari et al. showed that symptoms expectation regarding persisting symptoms following whiplash injuries and TBI is lower in Lithuania than in Canada (223,224), and other studies have shown that PCS (225) and possibly chronic WAD (226) are unusual in Lithuania. In another study, on a Canadian cohort, with a slightly different angle to the same phenomenon, Carroll et al., showed that persons expecting a rapid recovery recovered three times faster than those not expecting recovery after whiplash injury (227).

A reasonable guess is that people in western countries, like Sweden, do not anticipate whiplash injuries to follow after falls. The frequency of PTSD is lower and litigation is likely of less importance than after traffic crashes; thus implying a lower risk of persisting symptoms and consequent sick leave after falls.

**Clinical recommendations for MTBI and whiplash injury**

Based on clinical praxis and available research, the following items are important to consider at the emergency department…:

- CT and patient discharge is safe and more economical than admission for inpatient care after uncomplicated MTBI (228,229).
- Red flag symptoms indicating risk for neck fracture should be ruled out before discharging cases of whiplash injuries without X-ray or CT of the cervical spine. Preferably the Canadian C-spine rule may be used (230,231).
- The patients need oral and written information about the expected symptoms and the normal time to recovery following MTBI and whiplash injuries. Instructions on MTBI should also include recommendations for measures for preventing an additional MTBI in the weeks to follow.
- The oral and written information should address post-injury behaviour, which is generally to preserve normal comfortable physical activity and use prescription free pain medication if necessary.
- Most patients recover without persisting symptoms and expectations play a role in the development of such symptoms. Thus, firm information on the benign state of the conditions is called for.
- Persons within a risk group for prolonged recovery after MTBI (94) and whiplash injuries (203) may benefit from follow-up within a few weeks, thereby enabling early treatment of persisting symptoms.

…and at eventual follow-up in the primary health care:

- Symptoms, but also depression, anxiety, PTSD, expectations, and social aspects should be assessed.
- Pain and other symptoms as well as depression, anxiety, sleep disturbance, and PTSD should be treated.
- Persons with persistent symptomatology, in spite of treatment, should be referred to a rehabilitation clinic early in the course following MTBI and whiplash injuries.

## Strengths and limitations

*Setting*

The strength of this thesis is that it is based on solid epidemiological data from a defined population. Given the circumstances that UUH is the only hospital in the area, that it holds a robust trauma registration, and that cases of mild trauma are traditionally treated at the hospital, it seems reasonable to conclude that the epidemiological data gives a true picture of the ED-

panorama of TBI and whiplash injuries in the area. Apart from Umeå having a young, well-educated population with a high proportion of bicyclists that may influence some of the demographic factors, the generalizability to other Swedish cities is appraised to be good. The generalizability to other western, high-income countries with similar traffic density is probably also good.

As previously mentioned, missed cases are those not seeking acute medical attention for their injuries. That figure is about 30-40% of cases of MTBI (72,73). Regarding whiplash injuries, the figure is unknown; however, of people involved in rear end car crashes, i.e. exposed to a whiplash trauma, about 30-40% report a whiplash injury (232). It is likely to assume that a significant proportion of those not reporting injury still experience temporary neck pain and/or stiffness.

*Selection bias*

The problem with not including those not seeking health care is that this can create a selection bias: a difference between the study cohort and the population from which the cohort was selected (233). Factors suggested to denote not seeking medical care following MTBI are: injury at home, very mild TBI, old age, male gender, not being bothered by the symptoms, and quick symptom resolution (72,73). Patients not seeking medical care have fewer symptoms after three months than those who seek medical care (72). This may have influenced the results of this thesis in two ways: first, some of the mildest cases and some of the most unbothered patients were, consequently, not at all included in the trauma registration and second, the non-responders likely contain a proportion of the same category of patients as those mentioned in the first way; thus leaving a higher share of symptomatic patients to answer the survey. On the other hand, the non-responders probably contained patients with psychiatric issues and substance abuse, cases known to be at high risk for poor outcome, at least in the field of MTBI (137,140).

Another aspect of selection bias is that if patients with psychiatric issues, substance abuse, pre-injury TBI, and other pre-injury health-related problems are included, a very heterogeneous cohort will be created, thus making it difficult to draw conclusions. However, in a Finnish study in which the authors used strict exclusion criteria to create a homogenous, unbiased cohort, 95% of the patients had to be excluded (234).

*Post-concussion symptoms specificity*

Post-concussion symptoms are not specific for MTBI, in the present thesis a similar symptom distribution was found among cases of whiplash injuries. Previously, post-concussion symptoms have also been reported in healthy subjects, general trauma patients, psychiatric patients, neurology patients, pain patients, patients with minor medical issues, and insurance claimants

(109). This is a problem because questionnaires like the RPQ cannot be used to screen for cases of MTBI and from this thesis one cannot conclude what proportion of the symptoms reported are because of MTBI/whiplash injuries.

*The follow-up questionnaires*

In the present thesis, follow-ups of relatively large population-based cohorts of both cases of whiplash injuries and MTBI have been conducted. The fact that the cohorts are population based and prospective makes the studies strong. An excellent rate of objective data regarding long-term sick leave after whiplash injuries in 98% of the cases indicates reliable results. The response rate for the cases of MTBI was 80%, thus, indicating that the results are representative for the cohort. In the cases of whiplash injuries, the response rate was 61% and men were overrepresented among the non-responders; indicating a higher risk for selection bias.

Recall bias has been known to affect symptoms reporting in questionnaires in general (235). However, because the questionnaires used in this thesis focus on current symptoms, disability, and life satisfaction, the risk seems small. A more problematic bias is the "good old days bias" (236) meaning that persons who sustain an injury are likely to underestimate the problems or symptoms that he or she had prior to the injury event. This phenomenon has been shown to affect comparison between MTBI patients and control groups (236). Both the RPQ and the RHFUQ uses the question "compared with before the accident, do you now (i.e., over the last 24 hours) suffer from [any of the following symptoms]". This implies that the good old days bias may have increased symptoms reported by the cases of MTBI and whiplash injuries but not by the reference population.

**Future perspective**

In the field of epidemiology, recurring prospective research on defined populations is needed for surveillance of trends in incidences of TBI and whiplash injuries. Such research should, if possible, include pre-injury measurements of physical and mental health-status along with demographic factors. It should also assess if MTBI is present in cases of whiplash injuries and vice versa.

This thesis indicates that symptoms reported after MTBI and whiplash injuries overlap. A symmetrical follow-up of MTBI and whiplash injuries after inclusion in a cohort such as suggested above would be valuable. Follow-up optimally should be conducted close to baseline and then with regularity until several years following the injury event.

There is a lack of knowledge of effective interventions to prevent and treat persisting symptoms following MTBI (237) and whiplash injuries (238). This should be a prioritized research field.

# Conclusion

In conclusion, this thesis has shown that traumatic brain injuries (TBI) and whiplash injuries are common, especially among young people. The injuries render long-term symptoms, disability, and impaired life satisfaction in up to 50% of the cases. Symptoms exhibited are alike between the two types of injuries. The cost to society for loss of productivity is high, and there is a need for enhanced preventive measures aiming at reducing traffic-related injuries, sports injuries, alcohol-related injuries, and falls. Physical, mental, and social factors are important and should be addressed when examining and treating patients following TBI and whiplash injuries.

The two research questions of the preface were: why do some persons experience long-term symptoms and disability after TBI and whiplash injuries? And, what can we do about it? The answer to the first question, according to present knowledge, is that symptoms persist because of a combination of physical, psychological, and social factors – the so called bio-psychosocial model (239). In this model, different components can be more or less important to different individuals. Future research has to find out more about how to identify and how to treat individuals with different aetiology.

The answer to the second question is that, regardless of ideas for future research, and despite the fact that much of the aetiology of persisting problems following MTBI and whiplash injuries remain unknown, the patients have to be treated. Making efforts to treat whatever physical, psychological, social, or work-related factors are encountered can do this. As explained by Ruff, a patient-oriented approach is needed (93,240).

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# Appendix

**Appendix 1.** The injury surveillance form in use at the emergency department of Umeå University Hospital.

VÄSTERBOTTENS LÄNS LANDSTING

**INJURY SURVEILLANCE FORM**

| Date | Time | Person ID<br>Name<br>Address |
|---|---|---|
| Transport to hospital by | | |
| Ambulance ☐ | Helicopter ☐ | Profession |
| Taxi ☐ | Other ☐ | Telephone |

**PLEASE ANSWER THE FOLLOWING QUESTIONS BEFORE YOU MEET THE DOCTOR**

**When did the accident take place?** Year Month Day Time ____-_____-_____ Leisure time ☐ School time ☐ Work time ☐ Transport to/from work/school ☐

**Where did the accident take place?**
E.g.:
- Crossing Main Rd-Park Ave
- E4, 30 km south of Umeå
- Kitchen at home
- Workshop J.B.Corp. Umeå

_____

_____

**Describe how the accident happened** (Preferably draw a sketch)

E.g.:
- I was cycling westbound on Main Rd and collided with a car from the left on E4.
- Fell from the swing and hit the back of my head on some concrete.

_____

_____

_____

**What objects/substances (make) caused:**
The accident? _____
The injury? _____

**Vehicle accident** *Fill in information where applicable!*

Make/model year of vehicle _____
What was your position in/on the vehicle _____
What speed did you have at time of crash _____

| Did you have | Yes | No |
|---|---|---|
| Seat belt on | ☐ | ☐ |
| Head restraint | ☐ | ☐ |
| Helmet | ☐ | ☐ |
| Child seat | ☐ | ☐ |
| Did the airbag deploy | ☐ | ☐ |

Do you have any suggestions for preventive measures?

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**THANK YOU!**

*This information shall be used in our injury preventive work. The information is handled with the same professional secrecy as other medical files. We hope you will contribute!*