Whiplash-associated injuries and disorders
– Biomedical aspects of a multifaceted problem

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## Contents

Original papers

Definitions

Anatomic illustrations

1. Background
   1.1 Why study whiplash injuries and chronic post-traumatic syndrome? 15
   1.2 Description of the syndrome and etiological aspects 17
   1.3 The problem with the multi-faceted, cervical syndrome and the downside disadvantage of specialization 19
   1.4 Historical perspective and hypotheses concerning causes 20
       1.4.1 The post-traumatic syndrome including headache 20
       1.4.2 Otoneurological and brainstem symptoms including Wallenberg’s syndrome 22
       1.4.3 Epidemiology of minor neck and head injuries 25
       1.4.4 Early and late symptoms 27
       1.4.5 Pain, somatic symptoms, thoracic outlet syndrome (TOS) 29
   1.5 Objective/subjective 33
   1.6 Methodological considerations 33
   1.7 Population catchment areas 36

2. Aims of the thesis
   2.1 Overall aim 37
   2.2 Partial aims 37

3. Methods – Study populations
   3.1 Clinical studies – Paper I, II, III and VII
       3.1.1 Symptoms and physical findings (Paper I & II) 38
       3.1.2 Radiological study (II) 40
       3.1.3 Otoneurological study (III) 41
       3.1.4 Case report (VII) 42
   3.2 Epidemiological studies – Paper IV and V
       3.2.1 Reference populations, OHS, ULF (V) 43
       3.2.2 Injury types 44
       3.2.3 Syndromes 45
       3.2.4 Statistics 45
   3.3 Pathoanatomical studies – Paper VI and VII
       3.3.1 Case report (VII) 46

4. Results
   4.1 Clinical studies of chronic post-traumatic syndrome after whiplash-related injuries – Paper I, II, and III 48
4.1.1 Symptoms 48
4.1.2 Examination findings, physical examination (I) 48
4.1.3 X-ray findings (II) 49
4.1.4 Otoneurological findings (III) 50
4.2 Epidemiological studies of minor to moderate neck and head injuries – Paper IV and V 51
4.3 Hidden cervical spine injuries in traffic accident victims with skull fractures – Paper VI 52
   4.3.1 Autopsy findings 52
   4.3.2 X-ray findings 52
   4.3.3 Pathoanatomical findings during cryosectioning 52
4.4 Case report – Paper VII 53
   4.4.1 Clinical examinations 53
   4.4.2 Pathoanatomical findings 54
5. Conclusions and overall discussion 55
   5.1 Conclusions (common denominators, gender differences, and patterns) 55
   5.2 Methodological considerations 56
      5.2.1 The clinical studies 57
      5.2.2 The epidemiological studies 58
   5.3. Comparison with other studies 59
      5.3.1 Similarities and differences in WAD and PCS, “upper” cervical syndrome 60
      5.3.2 WAD and TOS, lower cervical syndrome, possible causes 63
      5.3.3 Cervical spine segmental mobility dysfunction 64
      5.3.4 Segmental dysfunction – as a biomedical explanatory model for development of all chronic post-traumatic symptoms – the root of all evil? 65
      5.3.5 Epidemiological results 68
      5.3.6 Gender differences – Do women sustain neck injuries easier than men do? 69
Reflections 72
Summary (in English) 75
Sammanfattning (summary in Swedish) 77
Acknowledgements 79
References 82
Original papers

This thesis is based on the following papers, which are referred to by their Roman numerals in the text. The papers (I – VII) are published separately in an Appendix which can be obtained from Centre for Musculoskeletal Research, National Institute for Working Life, Box 7654, SE-907 13 UMEA, Sweden, fax +46-90176116.

**Paper I**

**Paper II**

**Paper III**

**Paper IV**

**Paper V**
Bring G, Bring J, Westman G. Post-traumatic symptoms after mild – moderate head or neck injury – A 2-year follow-up questionnaire study of casualty register patients (submitted)

**Paper VI**

**Paper VII**
Definitions

Activity neurosis – tension syndrome due to fear to move
Afferent – pertaining to nerve impulses arising from the periphery and traversing in toward the central nervous system
AIS (Abbreviation Injury Scale) – scale for classification of acute injuries and their degree of severity where AIS 1 = slight injury and AIS 6 = death
Angiography – X-ray examination during which the blood vessels are filled with contrast – in order to facilitate visibility of structures
Anterior fusion – surgery technique, see disectomy
Arthrosis – chronic joint abnormalities that present as destruction of the articular cartilage, decrease of the gap in the joint and sometimes also in the formation of new bone around the joint surface; may be a residual condition after an infection, inflammation or damaging wear and tear; could also be the result of an isolated injury to the joint. Symptoms are usually stiffness and pain, however, the condition may exist without noticeable symptoms
Articular pillars – see fig. 2
Asthenia (neurasthenia) – the lack or loss of strength and energy; physical and mental; weakness; characterized by abnormal fatiguability
Ataxia – severe disturbance of the balance and coordination system, usually due to injury in the brainstem and/or cerebellum
Auscultation – the act of listening (mostly via a stethoscope) for sounds within the body mainly for ascertaining the condition of the heart, lungs, pulse, intestine, etc.
Axillary pouch – a soft tissue formation where the nerve roots are emerging from the spinal canal into the neuroforamina along the vertebral column
Axons – individual nerve fibres which extend from a nerve cell; these extensions can cover quite a distance, e.g., from the brain to the toes
Blockage – a term from orthopaedic (manual) medicine that is defined as reduced, or disturbed joint play. This can occur for many joints, but is especially observed for the facet joints in the vertebral column. Such blockages are believed to generate local pain symptoms, however, referred pain (see definition) also occurs. The cause of blockage is unclear, but different types of trauma are common triggering sources. Blockage can be offset with different kinds of treatment, with manipulation being the most effective. If the diagnosis is correct and the treatment adequately performed, abrupt release from symptoms occurs and joint play becomes normal. Also notice Lewit’s scheme for the vicious circles that can arise due to blockages (Lewit 1985, page 30)
Brachial plexus (plexus brachialis) – a network of nerves supplying the arm (see fig. 4A)
Brainstem – see figures 1A and 3C
CAT-scan – see Computerized
C – (abbreviation for cervical) – belonging to the cervical vertebrae; similarly, the thoracic vertebrae are abbreviated as T, the lumbar vertebrae as L, and the sacral as S
C1 – first cervical vertebra (atlas); C2 – second cervical vertebra (axis); C3 – third cervical vertebra, T1 – first thoracic vertebra, etc.
C1/C2 – joints between C1 and C2; as an alternative the segment that is formed by C1 and C2; may also be indicated by the upper joint’s designation, for example, the C1-segment regarding C1/C2, C2 regarding C2/C3, etc.

Cerebellum – the small brain, see fig. 1A

Cervical syndrome. – see page 8

Cervico-brachial – pertaining to the neck-shoulder-arm region

Cervico-cranial (German: zerviko-occipital) – pertaining to the neck-head region

Computerized tomography (CT) – computerized radiographic (X-ray) technique; also referred to as CAT scan (computerized axial tomography)

Cognitive – pertaining to ones ability to reason; the brain’s intellectual function

Concussion – (Latin, Swedish, German: commotio) – a head injury which usually arises when a deceleration/acceleration force against the head occurs and the result is disturbed consciousness; this might be followed by a characteristic picture of symptoms: PCS, postconcussion syndrome (Rutherford 1989), see page 9

Coordination (see also proprioception) – cooperative performance of different body structures for movement, for example, walking, eye movements, chewing, etc.

Cranial nerves – the 12 sense organ nerves of the brain including, for example, olfactory, optic and vestibular nerves (see fig. 3C)

Cryomicrotome – cutting device where the frozen specimens can be fixed and mechanically positioned in precise intervals in relation to the knife’s edge

Cryosectioning – a method often used to fixate and to cut a specimen, using a cryomicrotome, in order to cut it into thin sections for evaluation under the microscope. Also suitable for mapping of normal and pathologic anatomy due to maintaining the natural colour and shape of the tissue

Degenerative – opposite to generative which means to generate or to form. Degeneration is a natural process of ageing, regression, and changes due to turnover of tissues. For instance a degenerated disk has lost its resilience and ability to cushion impact; it is shrunken and bone deposits (spondylosis or osteophytes) are often present around the edges. Such deposits can interfere with the spinal canal and intervertebral foramen or the vertebral artery thereby creating secondary symptoms

Dens axis – see fig. 2

Dermatome patterns – specific neurological patterns of weakness, sensitivity loss, etc, following injury or compression of the nerve roots

Diffuse axonal injury – widespread, microscopic nerve injuries

Diskectomy + anterior fusion (for example, according to Cloward) – a surgical procedure where the disk is removed and the segment is fixed; this is performed in the treatment of a slipped disk that is symptomatic or to avoid painful segmental movements due to hypermobility or segmental instability

Dysarthria – slurring of speech due to dysfunction of certain cranial nerves

Dysfunction – disturbed function; the symptoms can present as chronic pain, numbness, tinnitus and other subjective sensations; also coordination (see definition) can be disturbed. In some cases dysfunction can be measured with different computerized registration methods such as ECG, EMG, posturography or oculomotor tests

ECG (electrocardiogram) – graphical representation of the heart muscles’ electrical activity

Efferent – pertaining to nerve impulses arising from the central nervous system and traversing out toward the periphery
Electronystagmography – graphical representation of the electrical activity of eye muscles in rapid voluntary movements
Epidural hematoma – bleeding to the anatomic space just outside the dura mater (hard membrane) surrounding the spinal cord (medulla)
Facet joints (also known as zygapophyseal joints) – see fig. 2
Functional X-rays – X-rays displaying the lateral view of the cervical vertebrae during maximal flexion (bending forwards) and extension (bending backwards) of the cervical spine (see fig. 9); movements can be performed actively (without force) or passively (as when an assistant moves the head into flexion and extension, respectively)
Fibromyalgia – see page 9
Fluoroscopy – a radiographic technique
Foramen intervertebrale – openings in the vertebrae where the segmental spinal nerves traverse out from the spinal canal (see fig. 2)
Foramen magnum – the hole in the skull base where the medulla (spinal cord) passes
Functional (pertaining to function) – during the 1900s an abused concept that implied non-organic or psychogenic which meant that it was entirely directed to mental hysteroid or hysterical reactions or symptoms
Functional images – functional X-rays – see fig. 9
Functional diagram – see fig. 13
Hypermobility (segmental excessive movability) – increased segmental movement that is significant, or relative as compared with adjacent segments; sometimes accompanied by segmental dysfunction = painful mechanical dysfunction of a motion segment
Hypomobility – decreased segmental movement – segmental blockages
Incidence – the proportion of new ‘cases’ in a population, occurring during a specific space of time, usually 1 year
Intima – the innermost layer of a blood vessel; an artery has three layers in it’s ‘wall’; in addition to the intima, an outer layer, the adventitia, and between these two a muscular layer which via sympathetic nerve innervation regulates the width of the artery, sometimes causing spasm, vascular cramping, etc.
Intervertebral foramina – foramen intervertebrale – see fig. 2
Kyphosis – unnatural posterior curvature of the cervical spine (visible via X-ray)
Labyrinth system – anatomic part of the balance system in the inner ear
Ligamentum flavum – longitudinal ligament along the back of the cervical spinal canal
Lordosis – the normal forward curvature (sway-back) of the cervical spine in relaxed position (see fig. 9)
Meniscoid synovial folds – small meniscus like folds of the membrane around the joints; these structures contain fat and nerve endings and are present in many joints, for example, the facet joints in the back (see Appendix, Paper VII, fig. 3D)
Morphology – science of structure mostly regarding tissue; morphometry refers to the measurements, reading and investigation of structures and tissues
MRI (Magnetic resonance imaging) – non-radiative examination that results in X-ray type images, where the soft tissues such as disks, brain, etc., are better visualized than by using normal X-rays
Myelography – ordinary X-ray following injection of contrast fluid into the spinal canal; this procedure facilitates visualization of possible disk protrusions, their pressure against the spinal marrow and other related changes
Myofascial pain – see fig. 4B
Nerve root symptoms, radicular symptoms – pain, weakness, decrease in sensitivity and/or reflexes, that follow the so called dermatome patterns which are specific for all nerve roots

Nerve tension test – see figures 8A and 8B

Neurosis – originally a term for an uncertain disorder of nerve function especially in the central nervous system; it has later come to represent a mild, mental condition of inadequacy

Occipital nerves – nerves running from the upper cervical segments to the base and back of the skull

Occiputo-atlanto-axial complex – see fig. 2

Oculomotor function – function of eye movements, which in turn is dependent on brainstem function

Orthopaedic medicine (OM) – manual medicine – a diagnostic and therapeutic technique working in several medical speciality fields, that are generally dedicated to the diagnosis and treatment of functional disorders of the musculoskeletal system (e.g., pain) when these conditions do not require surgical or specific rheumatological methods for treatment. The practitioner of OM works with a specific manual technique for examination thereby utilising knowledges in functional anatomy, neurophysiology and biomechanics to analyse disorders and their causes

Osteoarthrosis – see Arthrosis

Otoneurological – pertaining to the hearing and/or the balance system. These systems have a common cranial nucleus and nerve (VIII): n. stato-acusticus (see fig. 3C)

Pathoanatomy – Pathology – the science of diseases; the term pathological referring to deviation from the normal

PCS – post-concussion syndrome – see page 9

Percussion – the act of tapping or drumming the surface of the body, for example, the chest, and distinguishing by the sound the condition of underlying tissues or organs

Perineural – pertaining to the perineurium which is the connective tissue that surrounds nerve fibres; outside of this is the epineurium which surrounds bundles of nerve fibers

Plain radiography – ordinary X-ray

Pneumoencephalography – X-ray examination of the brain where the fluid around and in the brain has been displaced and air injected to improve the visibility of the contour of the cavities; (this procedure was very stressful for the patient; currently it is not needed with the emergence of computer X-rays and MRI)

Post-concussion syndrome – see PCS, page 9

Post-traumatic – occurring as a result of or after injury; originally aimed at physical injury, but in some cases nowadays in regard to mental damage, as, for example, in the conception of Post-Traumatic Stress Disorder (PTSD), see page 9

Posturography – graphical representation of postural correction movements during standing, with and without provoking dysequilibrium

Prevalence – the proportion of individuals who have a certain disease or symptom at a certain time

Prevertebral – on the anterior side of the vertebrae

Proprioception – the body’s sensory system for determining the position and movements of its parts relative to the body itself

Referred pain – trigger points – see fig. 4B

Root sleeve (forming the axillary pouch) – fibrous sheath surrounding the nerve roots where these leave the medulla (spinal cord)
**Saccades** – voluntary shift in ocular fixation, or automatic refixations (see fig. 14)

**Sagittal** – pertaining to a plane dividing the body into right and left sections; parallel with the long axis of the body

**Scalenectomy** – removal of parts of the scalene muscles, see fig. 4A

**Segmental** – pertaining to movement segments of the vertebrae, see C1/C2

**Segmental spreading of pain** – following other limits than dermatomes; more diffuse and hard to define, as for example, referred pain from facet joints or disks, or symptoms from brachial plexus, (where the different nerve roots have joined to a network and come out as four nerve stems. Furthermore, referred pain can arise from muscles and muscular attachments and then the picture varies even more

**Smooth pursuit eye movement** – automatic, coordinated eye movements (see fig. 14)

**Spinal processes** – see fig. 2

**Spondylosis** – bony derangements of disks and surrounding tissues due to trauma and/or ageing

**Subaxial** – below the 2nd vertebra (axis)

**Subluxation** – segmental derangement due to ligamentous injury

**Sympathetic nervous system** – part of the autonomous ’involuntary’ nervous system; the primitive nervous system, essential for the maintenance of vital functions such as heart rhythm, breathing, regulation of blood pressure, movement of the intestinal, etc; also serves for survival functions such as ’fight’, ’flight’ and other reflexory functions and bodily defenses as well as all muscular functions throughout the body (see figure, p. 7)

**Temporo-mandibular** – see TMJ

**Tinnitus** – spontaneous, disturbing sounds in the ear such as murmuring, buzzing, droning, humming, howling, etc.

**TMJ (temporo-mandibular joint)** – jaw-joint system of chewing, sucking, swallowing, speaking, mimicking, etc; the neuromuscular functions and coordination of the jaws are intimately connected with corresponding functions in the upper neck joints

**TOS** (thoracic outlet syndrome) – see page 8

**Transverse processes** – see fig. 2

**Trigger points** – see fig. 4B

**Uncovertebral joints** (so called) – ’stabilizing’ parts of the cervical vertebrae (see fig. 2)

**Vertebral artery** – supplying the brainstem, parts of the small brain and the spinal cord

**Vertigometry** – graphical representation of postural correction movements during standing, with and without provoking dysequilibrium

**Vestibular symptoms** – symptoms from the balance system; more specifically from the inner ear and/or the balance organ

**WAD** – whiplash-associated disorder

**Wallenberg’s syndrome** – see page 9

**Whiplash** – “Whiplash is an acceleration-deceleration mechanism of energy transfer to the neck. /.../ The impact may result in bony or soft-tissue injuries (whiplash injury), which in turn may lead to a variety of clinical manifestations (WAD)” (Quebec 1995). “The definition of whiplash injury /.../ is an injury to one or more elements of the cervical spine that arises from inertial forces being applied to the head /.../ that results in the perception of neck pain” (Barnsley et al 1994). Foreman & Croft (1995) prefer the term “cervical acceleration/deceleration (CAD) injury”. Others prefer “hyperextension- or hyperextension/hyperflexion injury” or “soft-tissue injury”. Terms like “strain” or “sprain injury” and “neck distorsion” can also be found.
**Cervical syndrome**, all the following symptoms may be included (Barré 1926, Decher 1969, Jackson 1977):

- Pain in the neck, shoulders, arms, thoracic spine, thorax (chest), lower back, pelvis, legs;
- Headache; e.g. tension type, greater occipital neuralgia, temporo-mandibular neuralgia, migraine, jaw-joint- and chewing-pain;
- Pain in the ear, in or behind the eye, in the face;
- Stiffness in the neck;
- Numbness, pricking and abnormal sensitivity (parasthesias) in the arms, fingers and face;
- Weakness in the neck, arms, and hands;
- Clumsiness; dropping things;
- Feeling of lump in the throat ('globus');
- Dizziness;
- Disturbance of balance, difficulties with balance in the dark and/or on uneven ground, vestibular dysfunction, brain stem dysfunction, neck receptor dysfunction, Barré syndrome;
- Visual disturbances, subjective reduction in the field of vision;
- Feeling sick (nausea), vomiting; Boats of fainting; seizures;
- Tinnitus buzzing sensation, fullness sensation of the ear, muffled feeling in the ear, subjective impairment of hearing, altered perception of sound;
- Drop outs;
- Blackouts;
- Extreme fatigue;
- Sleeping disorders; Disturbances from the autonomous nervous system, for example blurred vision, problems with accommodation, abnormal or irregular perspiration, disturbances in the regulation of temperature, irregular heart activity, palpitations, varying blood pressure;
- Problems with swallowing; Problems with the speech;
- Concentration and memory disturbances;
- Psychological symptoms;
- Difficulties in breathing;
- Disturbed proprioception, dropping things, stumbling, difficulties with precision work, problems with playing the violin, piano etc.


- Numbness;
- Diffuse pain in the arms;
- Headaches;
- Shoulder pain;
- Weakness in the arm and hand;
- Neck pain;
- Chest pain;
- Clumsiness, fumbling;
- Raynaud’s phenomena – cold, white fingers due to disturbed circulation, vascular spasm;
- Swelling in the hand and arm.
**PCS (post concussion syndrome)**, according to (Evans 1992a, Lidvall et al 1974, Rutherford 1989) the following symptoms commonly occur:

- Headaches;
- Dizziness, light-headedness;
- Balance difficulties, staggering;
- Sensitivity to light and sound;
- Buzzing, ringing sensation in the ears, hearing disturbances;
- Sleeping problems - trouble falling asleep, trouble staying asleep, early rising in the morning, need for too much sleep;
- Irritability;
- Difficulty concentrating;
- Difficulty with memory;
- Abnormal fatigue and tiredness;
- Clumsiness, dropping things;
- Change in handwriting;
- Diminished libido (sexual desire, lust), inability to enjoy sex, lack of ambition;
- Emotional instability;

**States of confusion;**
- Anxiety, worry;
- Mood swings;
- Difficulties with new or abstract tasks;
- Impaired ability to think logically;
- Blurring of vision;
- Double vision;
- Deteriorated simultaneous capacity;
- Forgetfulness;
- Changes in the personality;
- Intolerance to alcohol;
- Appetite changes;
- - loss;
- - gain;
- - craving for ‘junk food’ sweets;
- - weight changes;
- Fits of rage;
- Flashbacks (reliving the trauma);
- Headaches;

**Pain other than headache;**
- Unable to make or accomplish plans;
- Impaired intellectual capacity;
- Troubles expressing thoughts;
- Difficulties finding words;
- Slips of the tongue;
- Problems following a conversation;
- Physical and mental intolerance to stress;
- Restlessness/nervousness;
- Anxiety spells, fear - anxiety associated with the accident, - fear of leaving the house, - other unusual fears;
- Bouts of fainting;
- Seizures;
- Episodes of desorientation.

**PTSD (post-traumatic stress disorder)**, (Brett et al 1988, Søndergaard 1993)
(Overall definition: “Response to overwhelming environmental stress”)

- Being indifferent towards the surrounding world;
- Difficulty remembering;
- Loss of memory;
- Depression;
- Difficulty concentrating;
- Difficulty with memory;
- Abnormal fatigue and tiredness;
- Clumsiness, dropping things;
- Change in handwriting;
- Diminished libido (sexual desire, lust), inability to enjoy sex, lack of ambition;
- Emotional instability;

**Flashbacks (reliving the trauma);**
- Disturbances from the autonomous nervous system, e.g., impaired peripheral circulation, sweating, nausea, palpitations;
- Headaches;

**Fatigue;**
- Irritable colon;
- Muscular pain;
- Emotional instability;
- Trembling;
- Feeling of lump in the throat.

**Chronic fatigue syndrome (CFS)**, (Bannister 1988). Often described following a difficult infectious disease, for example encephalitis or meningitis, rheumatic fever or influenza

- Muscular pain;
- Weakness in the muscles;
- Extreme fatigue mostly in the legs but also in the arms and in the back especially following stress and strain;

**Problems concentrating;**
- Extreme exhaustion, in general;
- Numbness in the extremities and in the face;
- Double vision (diplopia);
- Blurred vision;

**Headache;**
- Perspiration;
- Cold fingers;
- Altered perception of sound;
- Emotional instability.

**PF – Primary fibromyalgi** (Olin 1995)

- Body pain (at least 11 of 18 bilateral, symmetrical tender points);
- Abnormal fatigue;
- Weakness;

**Condition worsened by change in the weather, static work load, cold, stress;**
- Sleeping problems;
- Headache, migraine;
- Stiffness;

**Dizziness;**
- Swelling;
- Numbness, prickling;
- Disturbed sense of smell;
- Impaired memory;
- Irritable colon.

**WS – Wallenberg’s syndrome**

The name for a family of symptoms characterized by certain neurological deficits. The cause is commonly associated with the blood flow occlusion of the posterior inferior cerebellar artery ('pica', see figure 3B) which supports part of the brainstem and the cerebellum (see figure 1A). Slurred speech and stumbling are examples of the symptoms. Often several cranial nerves are involved exhibiting paralysis, pain and other functional disturbances in the face and on one side of the body. The syndrome profile varies depending on differing anatomical variations of arterial network.
1. Corpus callosum
2. Thalamus
3. Hypothalamus
4. Basal Ganglia
5. Reticular system
6. Cerebellum

cross-section of white matter

**Figure 1A.** A cross-section of the brain

**Figure 1B.** The brain seen from below. The right temporal lobe and the right half of the cerebellum are cut off
The upper three cervical vertebrae seen from behind

C4 seen from above

C7 seen from above

The cervical spine seen from the right, from the second cervical vertebra (C2) to the first thoracic vertebra (T1)

**Figure 2.** The cervical spine and vertebrae
Figure 3 A. Diagram showing the more common lesions affecting the cervical spine following whiplash. (from Barnsley et al, Pain 1994, p. 290)

- Articular pillar fracture
- Hemarthrosis of the facet joint
- Rupture or tear of the facet joint capsule
- Fracture of the subchondral plate
- Contusion of the intraarticular meniscoid of the facet joint
- Fracture involving the articular surface (of the facet joint)
- Tear of the annulus fibrosus of the intervertebral disc
- Tear of the anterior longitudinal ligament
- Endplate avulsion/fracture
- Vertebral body fracture

Figure 3 B. The course of the left vertebral artery at the transitional point between the neck and the skull. The artery runs through the transverse processes from C6 to C1, then in an S-shaped coil (see picture), before running through tight muscular membranes and into the skull, after which the two arteries are joined to form the basilar artery
Figure 3 C. Brainstem seen from the front/beneath, with the distribution of the cranial nerves (I - XII)

Figure 3 D. Schematic drawing of simplified pathways from neck joints to abducens motoneurons and their interaction with the vestibulo-abducens reflex arc (in cat). Thick broken lines indicate cervical afferent pathways which converge on secondary vestibular neurons and facilitate them. AN: abducens nucleus. VN: vestibular nucleus. Inhibitory neurons are open and excitatory neurons are filled in black. To simplify the drawing commissural inhibitory pathways between right and left vestibular nuclei are not shown. (Adapted from Hikosaka & Maeda 1973)
Figure 4 A. Scalenus muscles and the brachial plexus (from Travell & Simons, 1983, p. 356)

Figure 4 B. Referred pain. Examples of referred pain and trigger points from the scalenus muscles (from Travell & Simons, 1983, p. 345)
1. Background

Wir sehen nur das was wir wissen
(We see only what we already know)
J W von Goethe

1.1 Why study whiplash injuries and chronic post-traumatic syndrome?

In the 1980’s, I spent several years working as a forensic pathologist, which entailed evaluating injuries on an almost daily basis, mostly traffic fatalities or fatalities due to other types of accidents or suicide. I knew hardly anything about whiplash injuries; the word itself I associated vaguely with a mechanism of neck injury. A friend of mine, a physical therapist as well as a lawyer, turned to me in the fall of 1983 for advice concerning a client, ÅN, who had tried for many years to gain compensation from his insurance company for a disability he claimed was the result of a traffic accident. My friend asked me to read through ÅN’s journal to see if there was anything from a medical point of view that I could add that might help his case with the insurance company. The following is a summary of what appeared in that journal.

Early one April morning in 1962, when ÅN was 31 years old, he was involved in a multi-car, rear-end collision while performing his duties as a part-time delivery truckdriver. He was apparently unconscious for a short time and was sent by ambulance to the nearest available hospital, where he was held for observation for some hours. He complained of a headache and received an injection to relieve the pain before being discharged with the diagnosis of concussion. He did not go directly home, however, but went instead to his regular job as a pre-school teacher. A couple of hours later he was forced to go home, due to severe headache. The headache did not disappear, and over the next few weeks, ÅN was easily fatigued and complained of dizziness in addition to experiencing pain in his neck and left arm. He had trouble meeting the demands of his jobs as a result. He was forced to leave his extra morning job as a truck driver immediately, but he also began experiencing difficulty at the daycare center. The noise that the children made began to bother him a great deal. The children’s parents also started to complain. They said that ÅN appeared intoxicated, despite the fact that he was a teetotaler, because he had begun to stagger and slur his words. His personality also changed; he became more and more sensitive and easily irritated, blowing up over nothing at all.

A few months after the accident he began noticing that he was seeing double when looking to one side. The headache continued to occur on a daily basis and was still severe. He went to see an ophthalmologist, who referred him to a neurology clinic for further examination, suspecting brainstem injury. The subsequent investigation went on for quite some time, in several different stages, without a definitive diagnosis being made. For various reasons ÅN did not agree to have a cerebral angiography or pneumoencephalography performed, which most likely contributed to the final diagnosis ‘Neurasthenia’. But at the time, a diagnosis of
MS (multiple sclerosis) was also considered. ÅN took early retirement at the age of 35 on the basis of disability due to his problems, but was denied compensation from the automobile insurance company since the presumed injury to the brain could not be confirmed. The comprehensive medical evaluations conducted in connection with the insurance claims hearings in both district and appellate court resulted in a judgement by the neurological expert witness, appointed by the Swedish National Board of Health and Safety, that ÅN’s disorder was due to a fear of motion or even a compensation neurosis resulting from anxiety and fear following a mild concussion.

According to the journal, ÅN’s list of symptoms was by this time extensive; more and more symptoms had gradually appeared. He exhibited fully developed signs of post-concussion syndrome (PCS) exhibiting daily, migraine-like attacks (which were worsened by physical activity), severe dizziness, sensitivity to light and noise, and so on. He also showed signs of injury to the brainstem and cerebellum, more resembling a Wallenberg’s syndrome, with central paralysis of one eye muscle, dysarthria (slurred speech), ataxia (loss of balance), and asymmetrical reflexes of the cornea and skin of the abdomen. In addition, he complained of pain in the neck, back, and the extremities of the left side of the body, a sensation of fullness in his left ear, subjective hearing loss of the left ear, numbness and clumsiness in his left hand, and also difficulty in sleeping, and impaired physical, intellectual, psychological, and emotional capacity. ÅN also blamed the divorce from his wife and subsequent separation from his four children upon the accident and resulting consequences.

In order to uncover proof of the small injury to the brainstem that he obviously had, I suggested performing a computerized axial tomography (CAT-scan) of the brain. (This method was not available in the beginning of the 1960’s.) Such a procedure was performed in the end of 1983, but – as expected – could not provide any pathological changes as proof of injury. ÅN’s lawyer and I sat with the neurosurgeon who was consulted for the CAT scan, and discussed new approaches. The lawyer/physical therapist was persistent, however, and kept asking if the whiplash injury could not be the cause of ÅN’s problems. The neurosurgeon and I looked at each other and shook our heads: we had no idea what she was talking about!

A month later I participated in a course on orthopaedic medicine dealing with diagnostics and treatments of pain and disturbances of the neck and the temporomandibular system. At this course, two whiplash victims with typical late whiplash disorders were presented, and both described a picture of their ailments that was more or less identical with ÅN’s. In my excitement, I could not wait to get home to share what I had learned, so I immediately rang to my lawyer friend and asked her to arrange a meeting with the client the following week.

In January of 1984 I examined ÅN for the first time. He displayed all the symptoms and findings that I had learned from the course were typical of patients suffering from chronic disorders following a whiplash injury. Among other things, I found a pronounced ‘blockage’ at the C1/C2-segment. This blockage was later confirmed and treated (with a manual mobilization technique) by my teacher from
the course. The day after this treatment, ÅN called and announced joyously that he had awoken without a headache for the first time in 22 years! The fullness sensation of the ear and the subjective deafness also disappeared at the same time. The dizziness reduced enough so that he could walk outdoors without support for the first time in many years. The asymmetrical reflexes were also normalized, which was confirmed by a neurosurgeon, who examined ÅN before and after the manipulation of his C1/C2 was performed.

During the first examination I was also able to diagnose a segmental hypermobility at the C5/C6 level. Renewed check-up of the journal showed that this hypermobility had been indicated on the functional X-rays that were performed in connection with the first neurological examination in the beginning of the 1960’s. Current X-rays showed no signs of degeneration of the segment. Some time after my examination, ÅN had surgery for removal of the injured disk and an anterior fusion of the segment. A few months later, the pain in the left arm and leg were gone. He said time and time again that he felt as if he had been given his life back. The insurance company, however, was still unwilling to recognize the connection between the whiplash injury in 1962 and the pension-determining disability, so ÅN’s financial situation remained disastrous.

My encounter with ÅN, combined with my increased knowledge in the field of orthopaedic medicine aroused my interest in the chronic post-traumatic syndrome following whiplash injuries. Along with my increased interest some pointed questions arose: Can a whiplash injury, without primary indications of brain trauma, cause headache, dizziness, and other PCS symptoms, including brainstem dysfunction? How can one explain the gradual appearance of symptoms? Why does the pain spread? Why is it that we doctors are not taught more about these injuries and their symptoms? Why are we not able to see what we do not already know? Are we blind or do we shut our eyes? Or do we not, really, want to know?

1.2 Description of the syndrome and etiological aspects

Many chronic conditions, whether caused by illness or injury, are characterized by certain combinations of symptoms, and for this reason are titled syndromes. One widely recognized example is AIDS, Acquired Immune Deficiency Syndrome, where, in addition to the constellation of symptoms, the cause of them was eventually also known. In this thesis on whiplash injuries and their consequences, several more or less clearly defined syndromes will be mentioned. Common to all of these syndromes, however, is that the mechanism behind the symptoms is often uncertain, unknown, or multi-faceted, even if a chronological connection to an injury or accident exists. In order to better illustrate the multi-faceted nature of whiplash related disorders and the difficulty in demarcating the syndrome, I have made a schematic synopsis of descriptions of some overlapping syndromes (see page 8 – 9). Note that all the symptoms listed on page 8 may occur as late symptoms resulting from a whiplash injury, even if some of them are very rare.
Figure 5. The image of the tree is used in an attempt to illustrate physicians’ view of a causal chain, cause – effect/symptom. In this image the trunk of the tree symbolizes the ‘evil’, in other words, the common cause behind all the symptoms (if they are plural). The network of branches is comprised of symptoms or complaints and, if present, examination findings, and the root system consists of the underlying or primary causes of the ‘evil’. In our search for the ‘root of the evil’, so to speak, we have a tendency to examine one root at a time, perhaps the root closest to us as specialists or closest to the surface. If we find the ‘problem’ in one of the somatic, bio-medical roots we are satisfied – and justifiably so. If we do not find the cause of the problem there, we search the next root and if we do not find it there we proceed to the next, and so on. What is difficult to see is that in many cases there are contributory causes existing in several roots or root systems and that root systems can have anastomoses, or connections. Roots can also be affected by what happens in the crown of the tree, i.e., by the symptoms. It is also difficult to know where to start to look for a cause when the flora of symptoms is lush and varied and the condition has been existent for a long time. Many cause-and-effect chains may have grown together by this stage. As the years pass, the tree grows, the crown and trunk as well as the root system, and the various complaints, patterns of motion, pain pathways, thoughts and behaviors all send down roots of their own. There is, of course, a risk that the original situation is now unclear and muddled, making it difficult for both doctor and patient to know where to begin and exactly which specialist should be consulted in order to gain proper treatment.

People who suffer from one or more of these troubling or bothersome late symptoms, chronic migrainous headache, for example, seek in various ways to rid
themselves of their affliction. If one knows the cause of a symptom, one can often help oneself; if not, a visit to the doctor is the next step. Doctors too, however, need to know what underlying malady is causing a specific symptom in order to be able to provide proper care. In our conceptual world, the term symptom (complaint) expresses the idea that something is wrong, an illness or injury, that something ‘evil’ is behind the symptom.

1.3 The problem with the multi-faceted, cervical syndrome and the downside disadvantage of specialization

For over 100 years, a successive and increasing specialization has occurred within the field of medicine. This specialization has contributed to fast development, both from a scientific and a technical/clinical point of view, and also to an impressive increase in the level of knowledge in each specialized area. In Sweden today, there are over 60 specialities and a number of sub-specialities. In an acute situation, the most common occurrence for the victim of a whiplash injury is to wind up at a general practitioner, an orthopaedic or a general surgeon. If the symptoms develops into a chronic phase, however, at least 20 of the other specialist fields can prove applicable and worth a consultation. An otoneurologist named Decher (1969), published a comprehensive, 185 page thick bibliography on the cervical syndrome, and wrote as follows in the foreword to the book (my own translation): “Since the cervical spine/neck region is central to many disciplines, this book is not only written for ear-nose-and-throat specialists, but to all concerned parties, especially orthopaedic surgeons, neurologists, radiologists, internists, general surgeons, and neurosurgeons”. The circumstance that this comprehensive work has not reached more widespread recognition in other parts of Europe and the USA might depend in part on the fact that it is published in German. A similar view was, however, presented by Jackson (1977) as early as the 1950’s, when the first edition of her book “The Cervical Syndrome” was released. In a scientific context, however, this has mostly been viewed as a topic for debate in the long since polarized American whiplash dialogue. Jackson maintains that, based on her many years of experience as an orthopaedic surgeon, at least 90% of all cervical syndromes are caused by whiplash injuries and other similar injuries due to accident, although the scientific proof, both for and against this stance, is today still weak (Quebec Task Force 1995b). The dispute might, however, be due to a definition problem; i.e., as long as you define the multi-faceted cervical syndrome according to Decher and Jackson, it seems quite obvious that it is a post-traumatic disorder. On the other hand many authors view WAD as a pure neck problem, a condition which, of course, might have other explanation.

The chronic whiplash patient with a wide range of diffuse and mixed physical and psychological symptoms, such as those that occur in the cervical syndrome, and with few or insignificant objective results from routine examination, does not fit into any available category. The diagnosis remains unclear, attempts at treatment fail, the thickness of the patient’s journal increases, insurance companies
grow suspicious, and the patient feels distrusted and misunderstood. The doctor, all along, feels frustration, not being able to help.

1.4 Historical perspective and hypotheses concerning causes

1.4.1 The post-traumatic syndrome including headache

Post-traumatic headache is a condition that has been recognized for over 100 years. Hippocrates believed that symptoms following an injury to the skull were due to fractures. In the 1200’s, Lanfrancus wrote about concussions with no fracture to the skull or injury to the skin. At least since the 1500’s there have been case descriptions of a post-traumatic condition and even fatality after trauma to the head with no visible injury to the skull or brain (Trimble 1981). In the end of the 1500’s, Paré noted that clinical symptoms could first appear quite some time after a head injury (Courville 1953). In the end of the 1700’s and the beginning of the 1800’s a number of reports of serious, long-term consequences of apparently minor injuries to the skull are presented (Trimble 1981). During the latter part of the 1800’s, when the railway system was being expanded, the number of derailments, collisions, and sudden braking accidents increased dramatically. With this came a corresponding increase in the number of debilitating head- and neck-injuries. Common to these injuries was a chronic state of disability, which was first observed after markedly minor trauma and non-apparent injuries, and characterized by a number of subjective complaints, summarized by the term “neurosis”. Symptoms such as headache, dizziness, reduced mental capacity, reduced vitality, personality changes, etc., could all be related to the nervous system. Their causative relation to an accident – beyond the chronological connection – was difficult to document objectively. A number of hypotheses sprouted concerning the cause and effect of these symptoms. According to one such hypothesis (Erichsen 1882), symptoms were caused solely by somatic injury to the brain or the medulla (spinal cord). In contrast, another hypothesis attributed solely the symptoms to greed or a hysterical personality (Page 1885). However, one opinion was that it was a combination of physiological and psychological factors (Janet 1893). For decades the debate raged for and against the importance that hysteria played in this context. It happens, though, that this was about the same time that Charcot’s and Freud’s breakthrough as men of psychiatric science occurred (Trimble 1981).

Those who favored an organic explanation coined the phrase “post-concussion syndrome” (PCS), which originally meant in part “concussion of the brain”, and partly “concussion of the spine”. A contributing cause to the extreme polarization of the different sides, hysterical versus non-hysterical, of this debate might be the fact that insurance coverage was introduced at about this time. This development allowed individuals to receive compensation in case of injury due to accident – first in job-related accidents, then later in traffic-related ones. This of course complicated the picture, involving the medical insurance aspects in a cryptic issue where the experts disagreed so strongly.
During the First World War, many cases of *post-traumatic neurosis* were defined as “war neurosis” or “shell shock” (Mott 1919), which meant that no signs of physical injury were deemed necessary in order for the symptoms to develop; a severe psychological trauma was viewed as ample cause. The disorder has had many names over the years (Table A) and in later years “traumatic neurosis” or “war neurosis” even has its own entry in the international psychiatric register of diagnoses, DSM-IV (American Psychiatric Association 1994): *post-traumatic stress disorder* (PTSD).

At about the same time in history, reports began to appear describing severe injuries of the *cervical* spine among fighter pilots who were launched by catapult from ships. The term “whiplash” was coined by Crowe (1928) to describe this common form of acceleration injury. Erichsen (1882) had previously noted that the risk of developing the *post-traumatic* psychoneurotic condition that he termed “railway spine” (since it was mostly the result of railway accidents in the 1800’s) increased if the impact came from behind. Later, the factor that most likely made the term whiplash a household word was a much publicized article in *JAMA* (the Journal of the American Medical Association) about cervical spine injury resulting from a rear-end collision in an automobile (Gay & Abbott 1953). The word whiplash has since proven impossible to cast off, despite concerted efforts, among others by the Quebec Task Force (1995b). It should be emphasized, however, that it is important that the term be limited to describing an injury mechanism, not a diagnosis or a condition. For the latter the terms whiplash related injuries and disorder, respectively, are preferable.

Hypothesizing about the causes of *post-traumatic* syndrome has continued throughout the 1900’s. Since the 1920’s, and to this day, the term “Syndrome

<table>
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<tr>
<th>Table A. Diagnostic terms used to describe the post-traumatic condition (Mendelson 1987):</th>
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<tr>
<td>Accident aboulia</td>
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<td>Accident neurosis</td>
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<td>Accident victim syndrome</td>
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<td>Aftermath neurosis</td>
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<td>American disease</td>
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<td>Attitudinal pathosis</td>
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<td>Compensation hysteria</td>
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<td>Compensationitis</td>
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<tr>
<td>Compensation neurosis</td>
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<td>Entitlement neurosis</td>
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<td>Erichsen’s disease</td>
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<td>Functional overlay</td>
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<td>Fright neurosis</td>
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<td>Greek disease</td>
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<td>Greenback neurosis</td>
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<td>Justice neurosis</td>
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<td>Litigation neurosis</td>
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<td>Mediterranean back</td>
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sympathique cervical postérieur de Barré-Lieu” (Barré 1926) is found in French literature on the subject. In this condition, arthrotic changes of the rear of the cervical spine causing disturbances in the sympathetic nervous system are central to the development of what in English and German literature is termed the “cervical syndrome”. Bärtchi-Rochaix (1949), who like Barré was a neurologist, noted that neck symptoms were often reported by patients suffering from PCS, otherwise dominated by migraine-like headaches. He conducted thorough studies of 33 such patients and all of them exhibited radiological changes (ostearthrosis) of their so-called uncovertebral joints in the mid-cervical spine (C2/C3 – C5/C6), in most cases on the same side as the symptoms. Raney and his collaborators (Raney et al 1949) showed disk injuries at these levels to be an important cause of post-traumatic headache after injury to the skull. Jackson (1977), during the 1940’s and 1950’s described the cervical syndrome after whiplash injury, and Decher (1969) did largely the same, without emphasizing the post-traumatic background. Both Jackson and Decher however, emphasized the complexity and array of symptoms displayed by the syndrome (see pp 8–9). Both also spoke of the hypothetical role of the vertebral artery in the syndrome’s development and the importance of the fact that the sympathetic nervous system has a rich network running through the walls of these arteries. The role that the vertebral artery might play in post-traumatic cervical syndromes is also emphasized by Braaf & Rosner (1958) in a review article about whiplash injuries.

1.4.2 Otoneurological and brainstem symptoms including Wallenberg’s syndrome

Some of the complaints following a concussion or neck injury are, respectively, of a vestibular/otoneurological nature; e.g., dizziness, tinnitus, fullness of the ear, and pain in or around the ears. Some authors maintain that such symptoms are especially common after whiplash injuries (Ryan & Cope 1955, Braaf & Rosner 1958, Jackson 1977). There are a number of theories concerning the origin of these symptoms. These theories have been characterized partly by the type of research or investigatory methods available. For this reason, previous studies of vestibular symptoms were primarily focused on the equilibrium organs and their functions (Lidvall et al 1974). Since direct injury to the vestibular organ or the vestibular nerve seldom occurs, it is very rare that any pathological findings have been recorded. As a result, the usual conclusion was that the symptoms must be psychosomatic, that is, of psychogenic origin (Lidvall et al 1974).

Other theories concerning the causes behind vestibular symptoms have focused on the brainstem and its central role in a number of functions important to both cervical syndrome and PCS (see pp 8–9). The brainstem consists of a large number of nerve paths carrying impulses to and from different parts of the brain. In the brainstem also the central cranial nerve nuclei are located and the integration of the impulses to and from the sensory organs, the musculo-skeletal system, and the different segments of the brain takes place. This means, among other things, that injuries or disturbances to the brainstem can manifest in a wide range of signs or symptoms of illness, both in terms of character and severity.
Both brainstem injury and dysfunction might be direct or indirect. Severe brainstem damage is, as a rule, fatal and there is rarely any problem to diagnose. Direct, minor injuries such as a result of mechanical over-extension due to acceleration-deceleration forces have been shown to occur in the form of hemorrhage or diffuse axonal injury (Ommaya 1966, Ommaya, Faas & Yarnell 1968, Ommaya & Gennarelli 1974). However, it is difficult to conduct this diagnosis on a living patient, most likely due to the diffuse and microscopical nature of axonal injury.


The injuries can be grouped as high (C0-C2 region) and low (usually C4-C6). The low injuries occur mostly in connection with fractures, luxations, or dislocations, in other words, in connection with more severe forces and strikingly often from side impacts, whereas the high injuries can result from relatively moderate forces, e.g., manipulation, or severe and long-term twisting of the neck, as well as from more severe forces. The mechanism for arterial injury from all forms of blunt force is usually tears of the intima (the innermost layer of the vascular wall).

This damage can lead to the formation of blood clots at the site, or blood can dissect or intrude between the vessel’s inner and outer layers and constrict the artery in this manner. Obstruction of the vessel, whether through the formation of clots or dissection, can lead to decreased blood flow to the brainstem and/or to the cerebellum. Usually, however, a singular constriction or obstruction of an artery passes with no evident symptoms, the blood supply from the collateral artery usually being sufficient. The risk of symptoms manifesting is greater, however, if both arteries are damaged at the same time or if the opposing artery is missing or quite narrow, which is not uncommon (von Lanz & Wachsmuth 1979, Gutmann 1983, Gutmann 1984). There are many examples of individual variations in the anatomy of the vascular system, which in some cases entails a risk for serious consequences if even one vessel is injured (von Lanz & Wachsmuth 1979).

One explanation for the delayed, more or less serious neurological symptoms, even death, after an apparently minor trauma to the cervical spine can be that an embolism, a detached blood clot, has been carried further down the artery. This can be particularly serious in concerning the vertebral artery, which supplies the brainstem and cerebellum with oxygen. Such an embolism can completely obstruct a blood vessel and cause an infarction in the area supplied by the vessel. Symptom delay might be a matter of hours, days, or even months (Tulyapronchote
et al 1994). One of the brain’s arterial branches reported to be especially vulnerable to this type of symptomatic embolism (and to a certain degree to dissecting vascular wall damage) is the 'pica' artery (posterior inferior cerebellar artery, see fig. 3B). Obstruction of this artery produces the more or less typical Wallenberg's syndrome, which comprises symptoms such as double vision, ataxia, and dysarthria (also see page 9).

Yet another hypothesis concerning the cause of PCS and the brainstem related symptoms in the cervical syndrome is the occurrence of spasms or temporary constriction of the vertebral artery as a result of increased irritability in the vertebral plexus, which is part of the sympathetic nervous system. This would also explain the periodic and often reversible character of the PCS symptoms. This hypothesis has been promoted by Barré (1926), Lieou (1928), Maspetiol (1960), Jackson (1977), and others.

There is also an early theory concerning the effect of neck reflexes on the appearance of post-traumatic syndrome with signs of brainstem dysfunction. These neck reflexes, which provide an important contribution to the function of our balance system with regards to the proprioception, from the body including the jaws and eyes in relation to the head, were described at length by Magnus (1924). McCouch and Adler (1932) showed that tonic neck reflexes have their end organs (receptors) in the joint capsules and ligaments of the three topmost cervical vertebrae. DeKleyn (1941) has described how the proprioceptors of the neck affect the outer eye muscles, which was later confirmed by Cohen (1961), Hikosaka and Maeda (1973), and others. Ryan and Cope (1955) coined the phrase “cervical vertigo”, based on the fact that dizziness is such a common symptom of various ailments of the cervical spine. Compere (1968) came out with a theory that post-traumatic symptoms connected to balance disturbances were a result of an imbalance in the central nervous system, which in turn was caused by an altered proprioceptive ‘input’ from the deep muscles and other tissues of the neck, and/or secondary to some form of effect on the vertebral artery (either via the sympathetic nerve plexus around the artery or mechanical obstruction of the same). This theory was adopted by Pang (1971), Rubin (1973) and Toglia (1976), all of whom were using electronystagmography in their studies of post-traumatic syndrome.

Hikosaka and Maeda (1973) showed in experiments on cats, how afferents from the three topmost cervical segments (fig. 3D) can affect one cranial nerve nucleus of the eye muscles and the vestibular nerve in various combinations of restriction and stimulation. This emphasizes even more so how intricate and complicated our system of balance and coordination is.

Hinoki (1985) used and developed optokinetic (having to do with the motion of the eye) testing methods and could present a basis for a theory that the cause of post-traumatic dizziness and balance impairment could be found in segmental instability in the cervical spine and sometimes in the lumbar spine. Nashner and Wolfson (1974), Lund and Broberg (1983), and Lund (1986), used computerized vertigometry to study the cervical spine’s effect on postural function. These tests
were later termed stabilometry (Roos 1991) and posturography (Aalto et al 1988, Pyykkö et al 1991).

**Oculomotor** tests, computerized analysis of the horizontal eye movements, including, voluntary saccades, fixation saccades, and smooth pursuit eye movement, provide an excellent tool for demonstrating brainstem and cerebellar injury (Balogh et al 1976, Henriksson et al 1980, Wennmo 1982). Over the last decades, these tests have been used to study the **proprioceptive** influence on eye movement in healthy individuals (Bles et al 1982, Bronstein & Hood 1986), and to illuminate the signs of brainstem dysfunction in patients with primary fibromyalgia (Rosenhall et al 1987).

The **cognitive** impairments and indications of injury which can be seen after a concussion or other head injury without noticeable brain damage have usually been of a transient nature (Rimel et al 1981, Kelly 1988). Gronwall (1989) was able to show, however, that such impairments exist among those continuing to complain of PCS symptoms. These patients, however, must be tested under special circumstances, since it is a question of a functional impairment in the central nervous system, which is often subtle, but sensitive to stress. Gronwall developed a special neuro-psychological test for this purpose, PASAT (Paced Auditory Serial Addition Task), which lately is being used more and more for testing whiplash patients with PCS symptoms.

In summation, there are stable foundations for the hypothesis that impaired brainstem function is pertinent to the vestibular and other otoneurological symptoms which occur in the post-traumatic syndrome following whiplash injury, and also to the eye-related symptoms which take on the characteristic of interfered proprioceptive functions. There is also reason to believe that these brainstem dysfunctions, at least in their milder forms, could be caused by disturbed ‘input’ from proprioceptors of the cervical spine.

In some patients, primarily those with more serious and apparent neurological symptoms and measurable cognitive function impairment, alternative explanations are probably more accurate, such as diffuse axonal injury to the brainstem or other parts of the central nervous system (Povlishock et al 1983), damage to the labyrinth system or the oval window in the inner ear (Chester 1991), or vascular and neurovascular mechanisms with secondary neurological damage or dysfunction as a result of such injury (Herrschaft 1971, Jackson 1977).

### 1.4.3 Epidemiology of minor neck and head injuries

Following the Second World War, there was a dramatic increase in the amount of automobile traffic in the West and an accompanying increase in the number of whiplash injuries (Gay & Abbott 1953). In experimental studies on primates, Macnab (1971), showed the occurrence of cervical spine injury, very difficult to detect, primarily to the disks, resulting from acceleration trauma equivalent to a rear-end collision. Abel (1971) described similar ‘occult’ injuries from the orthopaedic surgeon’s perspective. Bailey (1974) writes in a review-article about the
risk of lumbar spine injuries from whiplash trauma, and about delayed symptom development as a result of soft tissue injuries that do not heal properly.

In Sweden, whiplash injuries first gained attention in connection with the publication of Nygren’s thesis in 1984 on the safety of automobile interiors (Nygren 1984). Of the 70,000 rear-end collisions recorded per year, about 10% lead to reported neck injuries, and about 10% of these to a state of disability. Reliable incidence or prevalence statistics from that period are not available, however, since the term whiplash was almost unheard of.

Incidence estimations for minor injuries to the head also varied and were somewhat unreliable. Kraus and Nourjah (1989) give a figure of 1 – 2 per 1,000 per year and state that the incidence rate was twice as high among men as among women. This is in contrast to the statistics concerning whiplash injury, where women comprise more than half of the acutely injured in most studies (Gay & Abbott 1953, Schutt & Dohan, 1968, Hohl 1974, Balla 1980).

As to the prevalence of continued and chronic discomfort, the statistics vary even more. There are only a few prospective studies regarding the number of people with whiplash-related injuries, who develop chronic disorders, and these studies comprise mostly small patient populations. The definition of what comprises a whiplash injury, inclusion criteria and what can be counted as a resulting symptom of the injury, also varies greatly from study to study. The term prevalence itself has different definitions or none at all, with most authors describing the development of a chronic condition, but not relating this to an incidence. Table B shows the similarities and differences between the most important studies of the past 15 years, where the primary cohort is defined. As is shown, the prevalence varies between 14% and 67%.

Table B. 1983 – 1995 prevalence studies of chronic symptoms following WAD.
Population source: ER = hospital-based emergency ward; PC = primary care;
X = all patients who had a cervical spine X-ray after an accident;
insu = register from one insurance company;
MVA = motor vehicle accident; RE = only rear-end collisions in automobile; Cerv = all soft tissue injuries of the cervical spine;

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<thead>
<tr>
<th>Study</th>
<th>Publ Year</th>
<th>Study type</th>
<th>Population source</th>
<th>N</th>
<th>Follow-up time</th>
<th>Follow-up %</th>
<th>Prev WAD</th>
</tr>
</thead>
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<tr>
<td>Norris &amp; Watt</td>
<td>1983</td>
<td>prosp</td>
<td>ER RE</td>
<td>61</td>
<td>20 m</td>
<td>100</td>
<td>67</td>
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<tr>
<td>Deans et al</td>
<td>1987</td>
<td>retrosp</td>
<td>ER MVA</td>
<td>85</td>
<td>18 m</td>
<td>78</td>
<td>42</td>
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<tr>
<td>Miles et al</td>
<td>1988</td>
<td>prosp</td>
<td>X MVA</td>
<td>73</td>
<td>24 m</td>
<td>100</td>
<td>29</td>
</tr>
<tr>
<td>Dvorak et al</td>
<td>1989</td>
<td>retrosp</td>
<td>insu Cerv</td>
<td>320</td>
<td>- 1</td>
<td>65</td>
<td>30</td>
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<tr>
<td>Olsson et al</td>
<td>1990</td>
<td>prosp</td>
<td>ER MVA</td>
<td>33</td>
<td>12 m</td>
<td>100</td>
<td>36</td>
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<td>Hildingsson</td>
<td>1990</td>
<td>prosp</td>
<td>ER MVA</td>
<td>93</td>
<td>24 m</td>
<td>100</td>
<td>44</td>
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<tr>
<td>Pennie et al</td>
<td>1991</td>
<td>prosp</td>
<td>ER MVA</td>
<td>144</td>
<td>5 m</td>
<td>95</td>
<td>14</td>
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<tr>
<td>Radanov et al</td>
<td>1994</td>
<td>prosp</td>
<td>PC MVA</td>
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<td>12 m</td>
<td>72</td>
<td>28</td>
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<tr>
<td>DiStefano et al</td>
<td>1995</td>
<td>prosp</td>
<td>PC MVA</td>
<td>164</td>
<td>24 m</td>
<td>72</td>
<td>18</td>
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<td>Quebec Cohort</td>
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1) Time of follow-up not given
2) The prevalence figures are based on those compensated for income loss
All the other studies are based on WAD-symptoms reported at follow-up
During the same period that whiplash injuries increased in both absolute and relative numbers, the equivalent number of injuries to the head from traffic accidents decreased, especially those classed as moderate to severe. The prevalence of PCS however, as a result of minor head injuries has been relatively stable (Evans 1992a), but the figures are not easily comparable for the same reasons as for whiplash-associated injuries. Both conditions are also characterized by subjective discomfort, the individual symptoms of which are relatively common among the general population as a whole, requiring no injury of any form to arise (Evans 1992a, Evans 1992b).

Amphoux et al (1977) conducted a retrospective study of 808 people with injuries to the head (including moderate to severe injuries) from a total population of 10,381 factory workers, 440 of which exhibited or had exhibited PCS. (The results of other studies, see Kraus & Nourjah 1989, indicate that at least 75% of all injuries to the head are minor). The elapsed time between accident and examination varied from one to more than 16 years. On average, 40-50% had ongoing symptoms. Rutherford and colleagues (1978) showed that 14.5% of patients with mild head injuries still exhibited symptoms after one year. Fee & Rutherford (1988) reported 34% after three years, and in a study done by Edna (1987) about 25% of the patients exhibited continuing discomfort from an injury to the head that had occurred 3-5 years earlier.

The results of these studies indicate that minor injuries to the head, such as concussion, are a constant problem, with an incidence of about 1.5 per 1000 per year, and have a tendency in a number of cases (most likely at least 10%) to result in ongoing or long-term disorders.

Most of the early studies on whiplash injuries only describe those that resulted from rear-end automobile collisions (Gay & Abbott 1953, Macnab 1971), while Jackson (1977), for example, states that other types of traffic accidents and injuries can result in the same symptoms. Injuries to the head are also common in traffic accidents, but occur just as often in falls and other non-traffic related accidents (Kraus & Nourjah 1989), and have not been connected to a specific mechanism, in the way whiplash-associated injuries have been.

### 1.4.4 Early and late symptoms

The definition of whiplash, as well as concussion, vary, but the definitions given on page 8 and 9, respectively, are well grounded and accepted. The description of symptoms differs in the acute and chronic stages in both types of injuries. The acute symptoms following a whiplash injury are usually described in terms such as bewilderment, aching all over, but also stiffness, and pain in the neck which increases over the first few days. No immediate discomfort, but the symptoms appearing successively over the first hours or days was reported by some. Headache is common. A typical description is a severe headache upon waking the following morning and only being able to raise one’s head from the pillow with great effort. Nausea and mild dizziness can also occur. Pain and/or numbness that spreads out into the arms, sometimes out into the fingertips, also occurs, as does
difficulty in chewing or opening the mouth. A few of the injured experience difficulty in swallowing.

The acute complaints following a minor injury to the head are similar to those following a whiplash, although more acutely expressed (bewilderment, dizziness, nausea, and headache). By definition, a concussion should be accompanied by a loss or disturbance of consciousness for the diagnosis to be correct. Other symptoms that occur in connection with concussion, and not so much in connection with whiplash, are sensitivity to light and noise and extreme fatigue. There are no latent symptoms described in the acute stage of concussion. However, according to the author’s personal experiences, patients when asked, often describe stiffness and pain in the neck the morning after a concussion.

It is above all the chronic symptoms and disability that may occur after whiplash-associated injuries that have been difficult to explain and prove. As shown in sections 1.4.1. and 1.4.2., there have been many hypotheses but very little proof. The chronic symptoms following whiplash-related injury are also more numerous and much more pronounced than the acute symptoms (Braaf & Rosner 1958,

![Diagram of typical chronic symptoms after whiplash injury](image)

**Figure 6.** Typical chronic symptoms after whiplash injury. (The drawing is from the cover of “The Cervical syndrome” by Ruth Jackson, 4th edition, 1977, with permission from the publisher Charles C. Thomas, Springfield, Illinois)
Jackson 1977). This seems to also be true to a certain extent for PCS (Gronwall & Wrightson 1981, Rimel et al 1981). The variety of symptoms that are found in descriptions of chronic whiplash-associated disorders (WAD) are shown in fig. 6. There are about the same number of chronic complaints found in post-concussion syndrome (PCS) and the syndromes overlap a great deal (page 8). Chronic PCS as well has been described as being inexplicably more severe than would be expected from a minor head injury without objective indication of neurological damage (Miller 1961a, b).

1.4.5 Pain, somatic symptoms, thoracic outlet syndrome (TOS)
Even if some authors emphasize the polysymptomatic nature of the cervical syndrome (Braaf & Rosner 1958, Jackson 1977), it is neck pain, with or without radiation into the arms, that dominates our picture of this syndrome according to the literature (e.g., Gay & Abbott 1953). For this reason, most studies in this area have focused on the underlying cause of the pain, especially in the neck and shoulder, as well as any possible radiation of this pain down one or both arms. In cases where symptoms of neurological deficits occur, or where pain follows dermatome patterns, the logical choice has been to search for damaged or ruptured disks or compromised neuroforaminae in the cervical spine. Some studies have shown evidence of such explanations of the symptoms (Herzberger et al 1962, Harris, Hamblen & Ojemann 1962, Abel 1971, MacNab 1971, Bailey 1974) and as a result, the authors report being able to give surgical treatment for these symptoms (anterior fusion).

The typical description of pain resulting from whiplash injury is, however, of a more extensive and more diffuse character and the typical results of X-ray examination are no findings or findings without “clinical relevance”. In other words, there is as a rule no concrete link between the X-ray results and the complaints. It is common for the symptoms to be described in terms of varying radiation of pain and numbness, at times extending even out into the fingertips (most often in the outermost fingers, that is, the pinkie and ring finger). The arm and the hand “do not work”, with the discomfort increasing when one tries to work with the arms, especially above the plane of the shoulder. Clumsiness is often pronounced. This condition is sometimes summarized with the term TOS (see page 8). Initially, such complaints were thought to be caused by an extra rib, the so called cervical rib, which could pinch vessels and nerves when they pass under the collar bone and run down through the armpit out into the arm (see fig. 4A). Very few of these patients could be cured by the surgical removal of an extra rib (Coote 1861, Murphy 1906). Most of the patients showing post-traumatic occurrence of TOS, however, have no such extra rib. Adson and Coffey (1927) suspected some form of compression of the brachial plexus and performed a scalenectomy (the scalene muscles and the plexus are illustrated in fig. 4A). Based on theories that there was some form of dysfunction in the brachial plexus (Hardy et al 1962), various surgical procedures have been tried, for example scalenectomy, the removal of the foremost of the three parts of the scalene muscle (Sanders et al 1979). One alter-
native explanation was proposed by Nyström (1986), who surgically exposed the nerve plexus in the armpit of some patients with severe TOS-symptoms. By this means, he could observe the occurrence of a pronounced post-traumatic fibrosis (scarring of the connective tissue), which when removed (fibrolysis) caused the discomfort to cease. However, a long-term follow-up of these patients is not available, so the results are still inconclusive.

Elvey (1986) and Butler (1991) have also presented theories regarding nerve entrapment of the brachial plexus as a cause of post-traumatic TOS. A specific nerve tension test of this plexus, a sort of “arm-Lasègue”, analogous to the SLR (Straight Leg Raising test, testing the sciatic nerve in the leg), has proven to be a reliable function test (Elvey 1986, Butler 1991). In cases of positive reaction, i.e., the reproduction of pain in the plexus region, a dysfunction or disturbed function of the plexus is indicated, which is explained by the fact that the nerves are subjected to a non-physiological stretching and/or compression. This test is now regularly used in Sweden and other countries by physical therapists and other practitioners of manual/orthopaedic medicine (personal communication). Furthermore, Butler (1991) has developed a special therapy called “nerve mobilization” for treatment of TOS and other conditions with signs of “nerve entrapment”.

Other theories as to the cause of this type of pain and discomfort touch upon various segmental dysfunctional conditions of the cervical spine, including both hypo- and hypermobility, arthrotic changes in the facet- and/or uncovertebral joints, and occult, unstable disk injuries. Some of these conditions can be caused by structural changes, such as arthrosis or disk degeneration, which can be proven with X-ray techniques (Barré 1926, Bärtschi-Rochaix 1949, Herzberger et al 1962, Abel 1971, MacNab 1971, Bailey 1974).

Others, primarily those with a focus on manual techniques and orthopaedic medicine, have emphasized the importance of function and dysfunction in the locomotor system with regards to the appearance and, especially, the development of chronic pain (Lewit 1985, Hamberg 1986, Dvorak & Dvorak 1988). Decreased movement in a facet joint, a “blockage”, for example, is believed to result in a typical, segmental pain that momentarily disappears if movability is restored. Manipulation, the most common form of chiropractic treatment, is one example of this. Corresponding increased movability in a segment, as a result of injury or unfavourable, long-term stress or load upon the segment is believed to result in a different type of pain, called “ligament pain” by Lewit (1985). This type of pain can not be treated with manipulation. In fact, it is worsened by such treatment, at least temporarily, due to the fact that it is caused by too much strain and stress. One term coined during the 1980′s to describe this type of neck or back problem is “painful mechanical dysfunction of a motion segment” (Blomberg 1993). Lewit (1985) describes the connection between increased segmental and decreased segmental movability of the spine. He emphasizes the risk of falling into vicious circles if the cervical spine is subjected to injury of a whiplash character or concussion. For one group of patients examined the days following a concussion and complaining of headache and dizziness, all exhibited blockages between the
1st and 2nd cervical vertebra, and immediately after manipulation discomfort disappeared and movability was normalized. It is Lewit’s contention that there is a great risk that segmental blockage on the long run might lead to the development of hypermobility in an adjacent segment. Such a condition is markedly more difficult to treat than is the one-level hypomobility.

X-ray examinations of various forms seldom provide any grounds for proving somatic injury in whiplash-associated injuries. As a rule however, the cervical spine is examined with at least common X-rays in connection with or shortly after a visit to the emergency room. The purpose of this examination is primarily to rule out skeletal injuries (fractures) and dislocations (obvious ligament injuries). X-rays taken in lateral view with the patient’s head in a maximum forward and backward position, so called functional images, have been much used since the 1950’s (Fielding 1957, Buetti-Bäuml 1959, von Arlen 1978) in order to diagnose abnormal mobility between two vertebrae (segmental instability). Various models for analyzing the functional images have been presented (Fielding 1957, Buetti-Bäuml 1959, von Arlen 1978, Penning 1978, Henderson & Dormon 1985, Dvorak et al 1988). In these models, both decreased (hypomobility) and increased (hypermobility) mobility are examined, and the dynamics analyzed both segmentally and as a whole. The various measurement models have not, however, come to be used on any regular basis during routine examinations in radiology departments in Sweden. This is in part due to the fact that manual evaluation techniques and detailed analysis are time consuming. In later years, however, the process has become faster and more standardized through the use of computerized drafting boards and analytical programs (Dvorak et al 1988, Sluijter, Rohof & Vervest 1989). Though detailed functional analysis is still not a part of the daily routine, it has become routine to take functional images of almost all patients suffering from a whiplash-associated injury and who have continuing discomfort after 2-3 weeks (Quebec Task Force 1995b).

Another term central to the description of pain following a neck injury is myofascial pain, i.e., originating from the musculo-ligament parts of the locomotor system (Travell & Simons 1983). Referred pain and trigger point phenomenon, in or from various muscles have also been extensively described by Travell and Simons (1983). Pain from the entrapment or pinching of large or small nerve branches, e.g., the C1 or C2 nerves (Knight 1963, Bogduk 1981), restriction or constriction of a blood vessel or vascular spasm with impaired circulation in the muscles and nerves (Upton & McComas 1973, Blomberg 1976), tension headaches from stiff neck or jaw muscles (Wöber-Bingöl et al 1992), and disk- or ligament injuries (Kayfetz et al 1963, Lewit 1985), are all examples of more or less proven causes of pain in the chronic disorder following a whiplash injury. The search for the underlying cause of pain has focused more and more on dysfunctional conditions of the musculo-skeletal system and/or the nervous system. Clay and coworkers (1987) showed that the most important risk factor leading to the development of disability following a traffic accident is not the severity of the injury, measured by AIS or other injury scales, but rather whether or not the injury
affects parts of the locomotor system. Minor cervical spine injuries are especially responsible for a large portion of the long-term disability after car accidents (Clay, van Kampen & Hogerzeil 1987).

In Sweden, the view of post-traumatic syndrome is likely influenced by a neurologist with a great deal of interest in PCS, and who could prove that it was wrong to treat concussion with several weeks of bed rest, which had previously been common (Silfverskiöld 1951). In the 1950’s, a successful form of physical therapy (Silfverskiöld’s) that was based on reactivation and successive training to cure dizziness and other PCS-symptoms was introduced. Massage and activation of the neck muscles was a part of the treatment. Paradoxically, the neck’s role in the post-traumatic syndrome – with a few exceptions (Blomberg & Burén 1973, Blomberg 1976) – is still to a great extent unknown among Swedish neurologists. Instead, the consequences of the favorable results of this treatment (>90% of concussion cases were soon totally recovered if treated in time) was that the hypothesis of a psychosomatic mechanism behind PCS-symptoms was strengthened.

The attitude has been that those who do not respond favorably to the encouragement to return to work and other normal activities after a head or neck injury without neurological deficit symptoms, suffer from “activity neurosis” or have other psychological or financial reasons for their so called “pseudo-neurological” symptoms such as headache, dizziness, and tinnitus (Silfverskiöld 1985, Socialstyrelsen 1986), critically commented, though, by Bring (1985) and Blomberg (1985). A similar attitude has been presented previously from time to time in the scientific debate (Miller 1961a, Miller 1961b, Hodge 1971, Mills & Horne 1986), as well as recently (Schrader et al 1996). However, both criticism and counter arguments against such a simplified explanation have also arisen (Merskey & Woodforde 1972, Mendelson 1984, Radanov et al 1993, Barnsley, Lord & Bogduk 1994); most recently in the “letters to the editor” section of “The Lancet” (Björgen 1996, de Mol & Heijer 1996, Freeman & Croft 1996).

As can be seen from this historical exposé, post-traumatic syndrome has long been a hotly debated phenomenon. The shift in nomenclature, the wide range of hypotheses concerning the cause of the syndrome, and the very complex and comprehensive nature of the syndrome itself point to the fact that no simple, straightforward cause, with an injury to a specific structure or to a certain part of an organ, is apparent. Nor can it be a matter of “just” a psychosomatic or “trendy” ailment. The more one studies this multi-faceted problem, the more difficult it becomes to know anything for certain. The cervical spine, the nervous system, and the psyche, represents each very complex systems, both anatomically and physiologically. The interaction and integration between these systems is even more difficult to understand and describe. Added to the fact is that chronic pain, so crucial in this context, is itself a complicated and multi-faceted phenomenon, and is integrated in the functions of all of the organs of the body, both functionally and dysfunctionally. Interest in and knowledge about chronic pain has, in general, increased noticeably over the past 20 years. This is reflected by the number of related articles and books in the subject published in the past few years. The ana-
tomical and functional definitions used in this thesis have consequently been limited and simplified. Throughout the thesis, references are made to textbooks and other literature for a more thorough explanation of the terms and concepts used.

1.5 Objective/subjective

In addition to the complex and sometimes confusing array of symptoms presented in a fully developed case of cervical syndrome, it is important to note that most of the symptoms are subjective, that objective proof is lacking and the boundaries that separate the syndrome from other disorders are unclear (page 8). Furthermore, the very symptoms that are painful, even debilitating, for the patient often appear as diffuse and incomprehensible to the consulted physician. The easiest situation for the physician is when the condition is recognized immediately by description and/or appearance. Any examination that the physician performs is then chiefly characterized as being one of confirmation; the choice of treatment, or soothing or discouraging diagnostic information, respectively, becomes obvious. More common, however, is that the symptoms do not really relate to anything the physician has studied, but are still alarming enough to warrant investigation. The physician obtains one or several associations from the symptoms and the first clinical examination and progresses through a tree or pattern of answers to questions and tests that, in the best of cases, lead to a diagnosis and the accompanying correct treatment and/or decision. In this process – especially if it takes a long time or if the patient does not respond as expected to treatment – a physician often feels frustrated when faced with the choice of investigate too much or too little. Many whiplash patients with chronic, subjective suffering and no objective signs of disease or injury arouse this type of frustration in their physicians – who can, as pointed out above, be quite many in number. When, in addition, the demand for written reports, evaluation of disability and/or connection with a previous injury enter the picture, the doctor/patient relationship becomes even more complicated. To try and conduct any form of clinical research study in this very complex reality is, of course, not an easy task.

1.6 Methodological considerations

In the search for answers to my questions concerning ÅN’s case I went through a great deal of literature about whiplash injury, cervical syndrome, and posttraumatic headache. I published a literature review (Bring 1986) and an article contributing to the debate on the subject (Bring 1985). But the more I searched and read, the more confused I became. There seemed to be almost as many hypotheses concerning the cause and proper treatment of the ailments as there were authors. The more I immersed myself in the subject, the clearer the difficulties of finding an acceptable scientific design for studying the phenomenon became. Some examples:
A. The *pathoanatomical* tissue damage which could be demonstrated through experimental whiplash injury (Macnab 1971, and others) is almost impossible to show with X-ray or other examinations (note, in 1984, MR technology did not yet exist). The same would seem to be true for *concussion*: as soon as disturbances to the consciousness vanish there are as a rule no objectively demonstrable damage, even if the subjective symptoms are all too tangible for the afflicted.

B. Neither whiplash injuries nor *concussion* lead to death, which means that direct inspection of the injuries can not be performed, as is possible with severe injuries to the spinal cord or brain. As a rule, those few cases that are actually autopsied after this type of injury have other, more apparent injuries which make it difficult to motivate a detailed examination of the *brainstem* and *cervical* spine. On the other hand, the most common cause of whiplash injury, rear-end automobile collisions, rarely result in any other injuries, since all body parts but the cervical spine are so well protected from this type of accident.

C. The vast majority, probably 80-90%, of those subjected to a *concussion* or a neck injury of the whiplash type, recover completely, regardless of the treatment or type of care provided (Quebec Task Force 1995b). This means, among other things, that even the most scientifically designed prospective studies run the risk of being affected too strongly by external factors. It would most likely take a very long time indeed before such a study would comprise an unselected population large enough to draw general conclusions; so long, such that the study would risk no longer to be a good one.

D. It is hardly justifiable from an ethical or economic point of view to undertake comprehensive and perhaps invasive studies of patients with mild symptoms or none at all. This is especially true in light of the fact that there seems to be a consensus that the recommended type of acute treatment of whiplash injuries (and mild *concussion*) should be encouragement to return to normal activities, preferably within the week (Quebec Task Force 1995b).

E. The chronic, *post-traumatic* syndrome that may follow both whiplash injuries and trauma to the head is characterized by subjective symptoms with no objectively provable basis for a diagnosis of tissue damage. The cause of the chronic symptoms should therefore, in all likelihood, be sought in the form of some secondarily disturbed function; and how is one supposed to show *dysfunction* with *morphometric* methods? Add to this the fact that the *morphological* changes that can sometimes be shown to be the cause of the symptoms are often of a *degenerative* nature (Watkinson, Gargan & Bannister 1991), which means that they occur after some time, as a result of faulty healing of an injury. They are also hard to discern from similar changes that occur without any preceding trauma (Watkinson, Gargan & Bannister 1991).

Despite these methodological difficulties, I continued my search for possibilities to study the phenomenon of chronic *post-traumatic* syndrome following whiplash injuries. I was forced, however, to realize that it would be necessary to limit my perspective somewhat. With my background as a forensic *pathologist/morphologist* and my experience as a specialist in manual medicine with emphasis on the diagnosis of *dysfunction* in the locomotor apparatus as a point of departure, I chose to focus on the ‘biomedical roots’ of the tree (fig. 5). This meant that,
despite my insight into the multi-faceted nature of the problem, I did not go deeper into the psychosocial, psychological, or insurance system related causes of chronic post-traumatic syndrome following neck injuries.

I began in 1986 with a broad, clinical study of those patients with chronic disorders who had recently been referred to one of the clinics at the regional hospital in Umeå, Sweden. Many of these patients complained of dizziness and other ‘ear symptoms’ – some were actually referred to the ear clinic. At the same time, one of the ear specialists, who later became my co-author (BIW), noticed that several of her patients complaining of dizziness also complained of neck symptoms after whiplash-related injuries. The result was a cross-disciplinary study in co-operation with the ear, radiology, orthopaedics, neuro-surgical, and rehabilitation clinics. This research is presented in Paper I, II, and III (see Appendix).

While this study was being conducted, in 1988, I was asked by two orthopaedic surgery specialists, if, in my role as forensic pathologist, I would be interested in taking part in a study of neck injuries found among traffic fatalities. The purpose was to document any hidden injuries to the cervical spine, using the cryosection method developed by Rauschning (1983). This resulted in Paper VI, but also in Paper VII, since one of the patients that had been examined in the clinical, cross-discipline study (but not included in Paper I, II or III), died suddenly and was submitted to me for autopsy. This gave me the opportunity to examine his cervical spine with the cryosection method as well. At that time, in 1988, I had been exposed to theories among manual therapists that contended that fibrosis (i.e., connective tissue scarring) in and around the brachial plexus could cause diffuse symptoms of the arm, i.e., “TOS”. In keeping with these theories, I decided also to examine the nerve plexus of the patient’s arms (plexus brachialis, fig. 8B).

Questionnaires were planned in order to document the epidemiology of whiplash injuries, including incidence and prevalence of chronic symptoms after such injuries. It was natural to include minor concussions in the study, despite the fact that this went against the principle of focusing and specializing the field of study as far as possible in a scientific examination. It struck me as relevant to compare the two types of injuries, since there were so many similarities. A register of injuries due to accident has long been kept at the Umeå University Hospital. At the time of the study (1988-1990), there was a similar register in Skellefteå, Sweden. I used these two sources to gather the data for the register study in Paper IV and as a primary cohort to my questionnaire, which is presented in Paper V (see Appendix).
1.7 Population catchment areas

**Figure 7.** 1. Population catchment area of both the University Hospital and the State Institute of Forensic Pathology in Umeå (Paper I + II + III + VI)
2. Primary catchment areas of the hospitals in Skellefteå and Umeå, respectively (Paper IV + V)
2. Aims of the thesis

2.1 Overall aim

To investigate the biomedical aspects of the disabling chronic disorders that may quite often occur following what appears to be commonplace and slight accidents resulting in whiplash injury

2.2 Partial aims

To describe the symptoms, as well as the physiological, radiological and otoneurological findings associated with those whiplash injuries that manifest as severe chronic disorders; also to describe any interrelationship between these findings

To construct an epidemiological survey of light to moderate neck and head injuries by analyzing data from two hospital-based casualty registers combined with a follow-up questionnaire 1-3 years after injury; special emphasis is to be put on gender differences

To analyze similarities and differences of symptoms and disorders associated with neck injuries as compared to mild head injuries; also to highlight possible prognostic factors for the development of chronic problems

To describe the occurrence of neck injuries in road accidents that generate fatal head injuries, and how the pathoanatomical findings of such injuries relate to visible radiological signs
3. Methods – Study populations

Qui dolet meminit
(The one who is affected remembers)
Cicero

3.1 Clinical studies – Paper I, II, III and VII

With the aim to describe symptoms and examination findings in individuals with chronic whiplash-associated disorder, 30 patients with severe symptoms following an acceleration-deceleration injury at least six months prior were chosen. All of these had been referred by their general practitioners around the Swedish area of Norrland (Northern half of Sweden, fig. 7, area 1) to various clinics at Umeå University Hospital. Five patients who had a concomitant head injury were excluded. Two patients whose symptoms were not severe enough to warrant cervical myelography were also excluded from the study. One patient was excluded because of a technical problem with the myelography procedure itself.

The remaining 22 patients, 14 women and 8 men, participated in the study, which was conducted in 1986. The mean and median age at the time of the study was 38 years (20-53). The average time from accident to examination was five years (1-17). All of the patients had been healthy and working full time before the accident.

3.1.1 Symptoms and physical findings (Paper I & II)

An extensive physical examination according to the principles of orthopaedic (manual) medicine was conducted, including the following steps:

- Definition of the accident mechanism
- Detailed description of the origin of the symptoms, their development, duration, and character
- Manual examination according to Hamberg (1986), including
  - specific tests for muscle pain and muscle stiffness
  - segmental palpation and testing of the movability of the vertebrae, paying special attention to the patient’s pain reaction to the palpation and testing
  - neurological tests, especially a nerve tension test of the brachial plexus according to Elvey (1986).

A few details of the extended physical examination according to Hamberg (1986) require further comment.

- Segmental movability was tested by:
  - palpation of the transverse (lateral) processes of C1, palpation of the transverse and spinal processes, and of the facet joints of C2-C7
The patient’s pain reaction to palpation was defined as either:

a) immediate, but quickly receding, strong reaction, called a “jump reaction” (JR) and indicating hypomobility or “blockage” (Lewit 1985), or

b) delayed, residual, more dull reaction (DR), described by the patient as an unpleasant ache that increases gradually and often triggers symptoms, such as migraine-like headaches, dizziness, nausea, radiating pain and numbness, indicating hypermobility or “ligament pain” – as defined by Lewit (1985).

Restricted rotation of the upper cervical spine (C0-C3) was tested by first fully flexing (bending forward) the head (at this position the biomechanisms of the facet joints inhibits rotational movement of the cervical spine below C3), whereby range of movement, “end feel”, and side differences were noted. Restricted rotation below C3 was tested by first fully extending (bending backwards) the head, which biomechanically inhibits rotational movement above C3. Segmental tests for forward, backward, and sideways bending, as well as for translation, were performed in accordance with Dvorak & Dvorak (1988). These tests have also been described by Hamberg (1986). All of these tests were performed by Hamberg (JH) and myself (GB) – independently of each other and on separate occasions – and the results were documented.

Reaction to the specific nerve tension test performed according to Elvey (1986) and Butler (1991a, b) is considered positive when the patient reports pain over the brachial plexus and is interpreted as irritation of the plexus, (without necessarily indicating nerve damage, and therefore does not imply neurological deficit). The test is performed by placing the arm and hand in positions, that cause maximum stretching in the arm’s three nerve trunks and the cords of the brachial plexus (see fig. 8 A and 8B, radial, median, and ulnar nerve).

**Figure 8 A. Plexus brachialis (brachial plexus)**

**Fig 8 B. Performance of the specific nerve tension test.**
3.1.2 Radiological study (II)

All 22 patients also underwent X-ray examinations that included:
- common radiographs using antero-posterior (AP) and 45-degree oblique projections, as well as lateral projections, the latter in neutral, flexion, and extension positions (maximum active forward and backwards bending), so called functional images
- cervical myelography, in most cases combined with contrast-enhanced CAT Scan (CT) of the levels with ambiguous or suspected pathological changes.

All X-ray examinations were performed and evaluated within the framework of routine operations in the diagnostic neuroradiology department. The myelography was conducted using Omnipaque® contrast via a lumbar puncture. All X-ray images were examined by a neuroradiology specialist. One detail that can be said to lie outside of normal procedures was that in the referrals, we specifically asked for segmental deviations in the vertebrae’s positioning and mobility to be noted. Segmental translational movements greater than 3.5 mm were defined as signs of hypermobility (White III & Panjabi 1990).

The functional images (fig. 9) were also analyzed by GB at a later stage in accordance with Dvorak and coworkers (1988, 1993) in order to detect segmental hypomobility or hypermobility. Dvorak’s model for determining the rotation angle (RX) and translational mobility (AZ) between two adjacent vertebrae, from C1/C2 to C6/C7, was applied (fig. 10). This procedure was repeated 2-4 times with new measurements taken from each set of functional films, and the mean values were then calculated. In order to illustrate the mobility of the different segmental levels for each individual, and in order to simultaneously illustrate any abnormalities in mobility patterns, functional diagrams (fig. 13) were produced presenting each RX value in relation to normal values (±1SD + ±2SD respectively) (Dvorak 1988, active examination) for each segment. The graph was judged abnormal if the normally smooth line that joins the measurements for each segment was abruptly broken or formed a dogleg or zigzag, see fig. 13.

Figure 9. Acetate overlay tracing of flexion and extension radiographs. (With permission from the drawer, Arthur Croft)
3.1.3 Otoneurological study (III)
Twenty of the above mentioned 22 patients participated in the otoneurological study, together with 19 asymptomatic whiplash patients from the orthopaedic surgery department. Two of the patients in Paper I and II, (“T” and “T”, Appendix, pp 77 – 78) were excluded from this study because, in difference to all patients in the asymptomatic group, these two had not sustained their whiplash injuries in traffic accidents. The 19 asymptomatic patients had sought medical attention for neck complaints related to whiplash injuries at the emergency department in Umeå, six months previous to examination. At the time of the examination, however, none of these patients displayed any symptoms. The group comprised nine women and ten men and the median age was 25 years (ranging from 19 to 67). Twenty-five healthy individuals, who had not suffered any form of head or neck injury, comprised the control group. The mean age in the control group was 34 years (ranging from 25 to 40).

The main ingredient of the otoneurological examination was an oculomotor test (Bergenius 1984), i.e., a test of the brainstem functions as measured by eye movements. The examination requires that the subject sits still with a horizontal board of LEDs (light emitting diodes), which can be lit in different patterns, in front of their eyes. This simulates a point-light source that can be moved with different speeds, or that can jump from side to side with varying ‘viewing angles’ between movements. The subject is required to follow the light source without using head movements, and eye movements are registered using electronystagmographic methods with bitemporally placed surface electrodes. The entire examination is computerized (Bergenius 1984).

The examination measures smooth pursuit eye movements when a light source moves slowly and evenly from side to side, followed by a rapid return to the original start point (refixation saccade). So called voluntary saccades are then tested, which is when the line of sight is rapidly moved from side to side with varying angles (in this study, the angles were 20 degrees and 30 degrees from the midline).
When evaluating the results of the \textit{smooth pursuit} eye movement test, the relationship between the speed of the eyes and the light are expressed as a quotient called “gain” (normally around 1.0). The refixation saccade amplitude and the \textit{smooth pursuit} curve are also examined. Normally the curve should appear smooth and closely follow the movements of the light source. If any \textit{brainstem dysfunction} is present, such as reduced maximum eye movement velocity, then superimposed \textit{saccades} will be seen in an attempt to correct and to speed up the eye movements, which will produce a jumpy and step-like curve (see the example in the Results section, fig. 14).

When evaluating the voluntary, rapid eye movements – the \textit{saccades} – velocity, latency, and precision are measured. \textit{Brainstem dysfunction} can be seen, e.g., as “undershoot” or “overshoot” in the \textit{saccades}, as manifestation of low accuracy. In figure 14, both normal and \textit{pathological smooth pursuit} movement curves are illustrated.

\subsection*{3.1.4 Case report (VII)}

The patient presented in the case report (VII) underwent all the examinations described in Paper I, II, and III. This patient was among those excluded from Papers I, II, and III because he had sustained both whiplash and head injury.

\section*{3.2 Epidemiological studies – Paper IV and V}

Studies of minor to moderate ($\textit{AIS} \leq 2$) head and neck injury epidemiology were conducted via a review of the casualty register in the emergency rooms at Umeå and Skellefteå hospitals. These registers include all patients that seek medical attention at the emergency rooms after an accident. As well as the registration form, which includes questions about the time, place, and details of the accident, a copy of the emergency room journal is attached. I went through all the forms and journals produced during a two-year period (July 1988 – June 1990) and selected all the cases where the accident or symptoms described in the journal indicated a neck or minor head injury. Patients under 15 or over 65 were excluded, as were those with injuries noted as $\textit{AIS} \geq 3$. These limitations were chosen partly because > 95\% of neck injuries are sustained by persons in the selected age group (Quebec Task Force 1995a) and partly because it was relevant to the planned questionnaire study to exclude the youngest, oldest, and most severely injured patients.

The register study (IV) included 1,544 individuals and 1,568 accident related events. The questionnaire used for study V was sent to all the individuals from the group of 1,544 that could be traced ($n = 1,486$). The questionnaire (Q1) was first sent in May 1991 and a reminder was sent in August 1991. Approximately two years later, in November 1993, a new, shorter questionnaire (Q2) was sent out to those patients that could be traced among the non-responders to the Q1 (fig. 11).
The first questionnaire (Q1) included 12 questions about current chronic complaints, such as “Do you often suffer from headaches?” and “Are you often tired without reason?” These questions were identical to those used by Statshälsan (Statshälsan Occupational Health Service) (Kvist 1990) in order to enable a comparison with other populations. The questions in the second, much shorter questionnaire, which was sent out in November 1993, were very few. The recipients received a stamped postcard and only needed to check boxes as to whether they had symptoms such as headaches or pain in the neck that were related to the accident registered three to five years earlier. The number of responders to each questionnaire is presented in the flow chart, figure 11.

3.2.1 Reference populations, OHS, ULF (V)
The Statshälsan Occupational Health Service (OHS) reference population data (Kvist 1990), comprises 17,443 men and 17,701 women, all of whom – during the period from 1986 to 1989 – answered the same questions about chronic symptoms as the Q1-cohort in Paper V did. The mean age of this population was 42 years (range 15 – 65), all were gainfully employed and had been working for an average of 10.7 years. Both those with symptoms and without were included in that report. Another population study that was used for comparison of the prevalence of chronic symptoms was “Undersökningar av Levnadsförhållanden i Sverige, ULF”
(Survey of Living Conditions in Sweden) from Statistiska Centralbyråns, SCB (the National Bureau of Statistics), which included questions similar to four of the twelve questions about chronic complaints detailed in the Q1 questionnaire. The ULF Report (no. 76) outlines the state of public health situation in Sweden during the period 1988 to 1989 and is based on data elicited from approximately 13,000 randomly chosen interviewees, aged 16 years and above, and presented by age and gender (Statistic Sweden 1992).

3.2.2 Injury types
Injuries were classified according to the symptom descriptions and examination findings presented in the emergency room (ER) journals. In Paper IV, injuries were separated into “pure neck injuries” (whiplash and other indirect neck injuries), “pure head injuries” (concussion or suspected concussion), and “combination injuries” (where there were obvious signs of both neck and head injuries, for example, after falling and hitting the head and with documented symptoms of both concussion and neck pain.). Each group also included cases with additional injuries to the face, shoulder, chest, torso, or extremities.

In Paper V, the injuries were simply divided into neck and head injuries, in accordance with the neck injury definition supplied by Barnsley et al (1994). i.e., if initial neck injury symptoms were the reason for attention following acceleration/deceleration forces to the head and/or the cervical spine, then there is at least a neck injury whether a direct head injury is present or not. In practice, this means that the head injury group from study IV remains unaltered while the neck injury

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**Figure 12.** Types of accidents
group in study V is enlarged by the addition of those patients with combined injuries, which were in fact quite few (<8%).

The distribution of the various accident types in Paper IV and V is shown in Fig.12.

Vehicle accidents (Paper IV) and traffic accidents (Paper V) were also classified according to the direction of the force during the accident causing the injury, i.e., rear-end, front-end, or side collision, or if it was a single-car crash or two-wheeler accident (bicycle, moped, or motorcycle).

3.2.3 Syndromes
A condition requires several symptoms to merit being termed a syndrome. Generally, there are no well-defined boundaries for how many or exactly which symptoms should be included in different syndromes – and this is also the case for chronic WAD-syndrome and PCS. The classification of symptoms in the Q1 questionnaire study was based on what are traditionally considered physical, bodily symptoms and psychological, typical post-concussion symptoms (PCS). The former set of symptoms included pain in the neck, back, and other body parts, as well as numbness and tingling; while the latter (PCS) included headaches, difficulties in concentrating, dizziness, abnormal tiredness, irritability, and depression. Three symptoms that were included in the questions in Q1 were more difficult to categorize, as they are, if possible, even less specific, more subjective, and more difficult to define than the other nine. These symptoms were tension/restlessness, insomnia, and anxiety, and will be referred to as “other” symptoms, that is, neither physical nor PCS-related, despite the fact that many would like to link them to one group of symptoms or the other.

Comparisons were made of the “multiple symptom” (7 – 12), “symptom” (1 – 6), and “no-symptom” subgroups. The limit set between six and seven reported symptoms (out of twelve) was arbitrary.

3.2.4 Statistics
In Paper I we used Wilcoxon’s rank sum test in order to calculate the differences between men and women in terms of numbers and severity of symptoms displayed.

In Paper III, the test results for every patient were compared to the control group’s average result ±2 SD. The analysis was performed using the Mann-Whitney U-test.

In Paper IV and V, the Chi²-test or Fisher's exact test was used throughout – both according to Epi-Info – for all significance calculations for the differences between category frequency, proportions, incidences, and prevalences. The p-value used throughout was corrected in accordance with Yates’ method. In study V, logistic regression (SPSS) was used to analyze the risk factors for developing multiple symptoms.
3.3 Pathoanatomical studies – Paper VI and VII

In order to study the incidence and pathoanatomical manifestation of cervical spine injuries in combination with fatal head injuries, the victims of twenty-two consecutive traffic accidents were studied during routine autopsies. Five of the victims had been treated in neurointensive care wards – for a maximum of three days – and the others had died at the scene of the accident. The mean age was 26 years (range 14 to 55) and only three of the casualties were female.

All external injuries were noted and after removing the internal organs, performing an anterior examination of the cervical spine, and documenting the skull fractures, the cervical spine was frozen – together with the surrounding soft-tissues – from the base of the skull to the second thoracic vertebra, in situ, and in a stretched position. After freezing, the specimen was sawed out in block form, including approximately 3 – 4 centimeters of the base of the skull around the foramen magnum, and stored at -20 degrees Celcius.

With the aid of fluoroscopy, the specimen was positioned in an exact anatomical plane and X-rays were taken in standard AP and side projections as well as 45-degree oblique projections using fine-focus techniques. In order to visualize the separate left and right articular pillars, additional oblique 45-degree projections were used, combined with a 30-degree upward or downward tilt of the X-ray tube.

The X-ray images were examined by an experienced orthopaedic radiologist, who thoroughly analyzed them for fractures, dislocations, and signs of soft tissue damage. Six specimens, where the existence of injury was doubtful, were also examined using CAT Scan (CT).

The specimens were then embedded in high-viscosity carboxy-methyl-cellulose gel (CMC) and frozen within a supporting CMC ice block. The specimens were then serially sectioned in the sagittal plane using a specially modified plane cryomicrotome (Rauschning 1983), producing 5-10 micrometer thick sections of tissue with each cut. The specimen surfaces were carefully blown clean with compressed air at intervals of less than one millimeter. This process also thawed the surface, which was then coated with an ultra thin film of ethylene glycol. Photographic overviews were taken along with close-ups every millimeter. When noticing anything of particular interest, additional close-ups were taken using positive slide film.

In the cases where the X-ray and pathoanatomical findings did not agree, the X-ray findings were judged either false positive (when the findings were only present on the X-rays) or false negative. The X-rays were then re-examined by the radiologist one or two times. During the first re-examination, the radiologist was only given an indication as to the level of the discrepancy. During the second re-examination, the radiologist was supplied with the pathological image for comparison.

3.3.1 Case report (VII)

The autopsy proceedings, injury documentation, freezing of the cervical spine specimen, cryosectioning, and photographic procedures were the same in the case
study (VII) as in Paper VI. Both sides of the *brachial plexus* and surrounding tissues were also removed, snap frozen and stored at -70 degrees Celsius. This procedure was followed by cryosectioning, fixation, and routine staining, the latter in accordance with Mallory’s method for light microscopy.
4. Results

4.1 Clinical studies of chronic post-traumatic syndrome after whiplash-related injuries – Paper I, II, and III

4.1.1 Symptoms
Each patient received an identifying letter (A-V). The circumstances surrounding each patient’s accident are shown in Figure 1 in Paper I (Appendix, page 77). Seven of the patients experienced immediate neck and head complaints. However, in most cases, the development of symptoms was more slowly incremental and it took on average several hours before the acute symptoms peaked. In a typical case, the patient would wake the day after the accident with a stiff neck and a severe headache. The later symptoms were greater in number and more disabling than the early symptoms and many patients spoke of a second interval after the accident, when the symptoms were less pronounced. This period came about when the acute symptoms began to wane. The patient attempted then to return to normal activities, however, the pain then returned and were more pronounced and new symptoms arose. A number of patients described a new, banal trauma that instigated the later problems. All 22 patients described a wide range of chronic symptoms, each patient fulfilled the criteria for a post-concussion syndrome (PCS, page 9), and all but one patient suffered from headaches that were most often severe. Eighteen patients described the headaches as migraine-like and all stated that physical activity worsened their symptoms for a shorter or longer period. Typical for the chronic symptoms were powerful fluctuations – better days intertwined with terribly bad days – which provided a stressful and destructive experience.

4.1.2 Examination findings, physical examination (I)
All the patients showed delayed pain reaction (DR, see Appendix, Paper I) when the middle cervical spine (C3/C4 – C5/C6) was examined and signs of segmental hypermobility/dysfunction on at least one of these segmental levels. Palpation of the upper (C0 – C2) and lower (C6 – T1) cervical spine mostly caused a “jump reaction” (JR, see Appendix, Paper I) and at the movability test signs of restricted mobility (hypomobility – segmental dysfunction) were found.

None of the patients showed any sign of neurological deficits or typical nerve root symptoms. The nerve tension test indicated irritation or dysfunction in the brachial plexus, single or double-sided, in half (12) of the patients (Table I and II, Appendix, Paper I).
4.1.3 X-ray findings (II)

The plain X-ray images showed a straightened lordosis in all 22 patients’ cervical spines. Nineteen patients showed indications or evidence of segmental kyphosis (at the C3/C4, C4/C5 or C5/C6 level, mostly in flexion). The majority showed decreased mobility of the cervical spine as a whole. Other X-ray findings are shown in Table 1 and Table 2 in Paper II (Appendix p. 87). Detailed analysis of the functional images showed a consistent pattern of dysfunction in the form of hypomobility in the two top segments and the two bottom segments. Hypermobility was also seen in the rotational measurement (RX, fig. 10), either significantly (when the angular value deviated from the normal by more than 2 SD) or relatively (in relation to the surrounding segments). Signs of hypermobility, either in the RX measurement or in the AZ measurement (fig. 10), were most common in the C3/C4 and/or C4/C5 segments.

![Diagram](image1.png)

**Figure 13.** Segmental function diagrams. The two uppermost diagrams are from Paper II. The bottom diagrams is from the case report. Normal values are from Dvorak et al. (1988). RE = rear-end collision, TO = turn over.
Typical examples of individual patterns of dysfunction are shown in the segmental rotational mobility diagrams in Figure 13.

Correlation between the clinical and radiological findings of regional and segmental hypo- and hypermobility was good (as seen in Table 3, Appendix, p. 88).

4.1.4 Otoneurological findings (III)
Eighteen of the twenty patients with chronic symptoms presented oculomotor function disorders. For the control group or the group of 19 asymptomatic patients, there were no indications of oculomotor dysfunction when smooth pursuit eye movement and saccade tests were performed. The type of disorder for the symptomatic patients varied, including pathological smooth pursuit movements, low ‘gain’, poor precision, and low maximum velocity in the saccades. Additionally, many disturbances were asymmetric. For most of the dysfunctions, there were statistically significant differences, on a group level, between the symptomatic patient group and the other two groups (see fig. 1 – 4 in Paper III, Appendix p. 96). Four of the patients (M, Q, U, and V) showed more severe signs of oculomotor dysfunction, indicating brainstem injury (fig. 14). All four were females of varying age at the time of the accident (19 – 48 years), they had all suffered neck injuries in accidents with high energy impacts (two were hit from behind, one had driven off the road and hit a tree, and one had been in a car that somersaulted – all four accidents involved high speeds), and each had obvious symptoms of neck injuries directly after the accident. At the time of the study, all four also had clear signs of segmental instability/disc injury at two levels between C3/C4 and C5/C6, which in each case indicated a need for surgery and anterior fusion on these levels.

**Figure 14.** Normal (the two on top) and pathological (down) smooth pursuit eye movements at oculomotor test. The patient (Q) is presented in the Appendix, p. 78.
4.2 Epidemiological studies of minor to moderate neck and head injuries – Paper IV and V

In the register study of minor to moderate neck and head injuries (Paper IV), women accounted for a larger proportion of neck injuries than men. The age and gender adjusted incidence indicated that younger men (15 – 17 years old) tended to sustain these injuries less often than women of the same age (fig. 2, Appendix, page 104). This gender difference was not, however, statistically significant. A similar tendency, also not statistically significant, was seen in the 39 – 53 years age group, where the incidence of neck injuries was higher among women than among men (fig. 2, Appendix, p. 104).

Statistically significant gender differences did appear, however, when the injuries were divided according to accident type. Consequently, among traffic accidents, different patterns appeared for men and women, with men primarily sustaining injuries as vehicle drivers involved in single vehicle or head-on collisions, while women dominated injuries among vehicle passengers and pedestrians. Women were also more often injured in accidents involving collisions from behind or the side (figures 4, 5, and 6, Appendix, pp 105 – 106).

Similar gender related patterns were also seen for sports related accidents, where women (girls) more often sustained their injuries from falls in individual sports, such as horse riding and gymnastics, while men (boys) mostly injured themselves during team sports, such as hockey and soccer. In accidents that were not related to traffic or sports (“other”), gender related patterns were also seen: men often sustained injuries after colliding with other men or objects – both during work and leisure activities (Table 2, page 107). In the latter cases, alcohol was often involved. Women more often sustained injuries during falls, often due to falling in the home or on the way to or from home, and rarely alcohol related.

The results of the questionnaire study (Paper V) indicated that headaches and other PCS-symptoms were more common after neck injuries than after head injuries and that they were more common among women than among men (Fig. 1 and Table 2, Appendix, pp 118 – 119). Physical symptoms (pain, numbness), for the most part connected to neck injuries, were also common after “pure” head injuries (Fig. 1, page 118). More women than men reported symptoms and they reported significantly more symptoms than the men did (Table 2 and Fig. 2, Appendix, page 119). Women also answered the questionnaires to a significantly greater extent than the men did (Table 1, Appendix, page 117). Significant risk factors that led to reports of a high number of chronic symptoms, i.e., between seven and 12, after neck or head injuries were female gender, older age, neck injury, and the occurrence of traffic accidents. Additional factors among the traffic accident group included rear-end and frontal collisions. Female gender was, however, the only risk factor in this study that remained regardless of the division of other risk factors into subgroups (Table 3, Appendix, page 120).
4.3 Hidden cervical spine injuries in traffic accident victims with skull fractures – Paper VI

4.3.1 Autopsy findings
Details about age, gender, road-user type, accident type, and autopsy findings for each of the accident victims are summarized in Table 1 in Paper VI, Appendix, page 130. Only three victims were female (aged 17, 18, and 19) and all three had been killed as unprotected road-users. One was a pedestrian (from a total of two), one was a cyclist (from a total of two), and one was an automobile passenger who had been thrown out of the vehicle (from a total of two).

All three women sustained skull base fractures, as had all but two of the men. The two men without skull base fractures sustained other skull fractures (calvarium fractures) together with other multiple injuries, including facial fractures. During the autopsies of six of the men with basal skull fractures, no other injuries could be determined.

In two cases, where both patients had died after 2 – 3 days in intensive care, hemorrhaging was found on the anterior side of the vertebral column (prevertebral), extending down to the brachial plexus, single-sided in one case and double-sided in the other.

4.3.2 X-ray findings
The few X-ray findings that were deduced are displayed in Table 2 (Paper VI, Appendix, page 131). The table also indicates the false positive (five cases) and false negative (two cases) fracture findings. All the injuries detected during frozen cervical spine specimen dissection are also listed in the same table. Only three “true” fractures could be detected on the X-ray images and all of these were fractures of the dens axis (C2). The false fracture findings were found in the more anatomically complex structures, which are more difficult to judge on X-ray images (for example, those in facet joints, vertebral end-plates, or transverse processes, see fig. 2).

4.3.3 Pathoanatomical findings during cryosectioning
All 22 cervical spine specimens showed hidden injuries, in most cases multiple soft-tissue injuries. Only a fraction of the injuries could be detected during routine autopsies or using X-ray images, despite the high quality involved (see Appendix, Fig. 1, page 129 and Table 2, page 130). The most common injuries/locations were damage to the uncovertebral and facet joints (77 and 69 injuries, respectively), disk lesions (28 ruptures), and ligamentum-flavum ruptures (8). Thirteen specimens contained a total of 44 injuries in the occiputo-atlanto-axial-complex (C0-C1-C2), mostly ruptures in ligaments and joint capsules.

The segmental distribution of the subaxial (C2 to T1) soft tissue injuries is presented graphically in Fig 5, Paper VI, (Appendix, page 133). None of these injuries could be detected on X-rays, not even during a second or third examination with knowledge of the injury location.
Only four specimens did not show any signs of uncovertebral joint injuries. Three of these displayed facet joint injuries and the fourth showed an isolated epidural hematoma. Only three specimens had no facet joint injuries and one of these was the specimen with the isolated epidural hematoma. The other two specimens contained ten and six uncovertebral injuries, respectively. All three specimens from women had facet joint damage and two of these had multiple facet joint injuries combined with multiple uncovertebral injuries. The third had facet joint damage combined with multiple disk injuries. One specimen, from a 23-year old pedestrian, contained a pure traumatic slipped disk (C5/C6) without any degenerative disk alterations (Fig 11, Paper VI, page 135). The 69 facet joint injuries commonly included injury to the meniscoids (Fig 7, Paper VI, page 134).

4.4 Case report – Paper VII

4.4.1 Clinical examinations

The patient in this case description (Paper VII) was examined in the same manner as the patients described in Paper I, II, and III. He had developed typical WAD-complaints after a traffic accident where he was thrown out of a bus and was unconscious for a short period. The injury was not initially diagnosed as a typical whiplash injury, but rather as a concussion with initial stiffness and pain in the neck. However, he displayed the same range of chronic symptoms as the other patients with PCS-symptoms and severe headaches that were quite often migraine-like and, like the other 22, he explained that physical activity intensified certain symptoms dramatically.

The patient’s later symptoms were greater in number and much more disabling than his initial symptoms, which also were in accordance with the 22 patients in study I. He also described a rather long period, approximately three years after the accident, during which his symptoms were few and mild. After that period his condition suddenly worsened drastically with severe dizziness and cranial nerve disturbances (of the IX\textsuperscript{th}, X\textsuperscript{th}, and XI\textsuperscript{th} cranial nerves). The etiological diagnosis of these symptoms could never be established; the hypothetical diagnosis was “prevertebral swelling”.

Just as the 22 patients in Paper I and II, this patient showed a delayed pain reaction to palpation of the middle cervical facet joints (C3/C4 – C5/C6). When the patient turned his head to the right and when segmental mobility at the C3 – C4 level was tested, this resulted in severe dizziness and a tendency to faint. He also displayed a “jump reaction” (see page 76, Appendix, paper I) and restricted mobility (hypomobility) during palpation and testing of the upper (C0 – C2) and lower (C6 – T1) segments of the cervical spine.

The patient also complained of diffuse pain and numbness, as well as clumsiness, in his left arm and hand. He displayed a positive nerve tension test and pronounced sensitivity to palpation of the left brachial plexus.

According to radiological evidence, there were signs of a degenerated and collapsed disk at the C5/C6 level, together with constriction of the right
intervertebral nerve foramen and a deformed root sleeve on the same side at the C6 level (Fig. 1D in Paper VII, Appendix, page 145). The functional images showed no measurable segmental instability, but the functional diagram showed similar dysfunctional patterns seen in the patients in Paper II (Fig. 13). All the types of oculomotor dysfunctions that were registered in patients in Paper III were also seen in this patient.

4.4.2 Pathoanatomical findings
Aside from disk degeneration and constriction of the right intervertebral foramen (see figures 2 and 3C, Appendix, pp 146 - 147,) which had already been detected during the radiological examination, cryosectioning of the cervical spine led to the discovery of pronounced pathoanatomical changes. I.e., uncovertebral joint spondylosis, right-sided facet joint osteoarthritis with subluxation, and fibrous degeneration of the meniscoid at the C5/C6 level (fig. 3D, Paper VII, Appendix, page 147). The left brachial plexus displayed more pronounced perineural fibrosis in comparison to the right side (fig. 4, Appendix, page 146).
5. Conclusions and overall discussion

Every part of the hologram re-creates the whole
From: The holographic paradigm and other paradoxes
Ken Wilber (Ed)

5.1 Conclusions (common denominators, gender differences, and patterns)

In a selected group of patients with severe, chronic disorders after whiplash-related injuries without head injuries, high frequencies of the following were observed:

- A wide range of cervical syndrome symptoms, including headaches and other post-concussion (PCS) symptoms (Paper I – III);
- Pronounced cervico-brachial (TOS) symptoms (Paper I & II)
- Signs of dysfunctional brainstem function in the form of asymmetrical alterations observed during an oculomotor test (Paper III)
- Signs of dysfunction in the segmental mobility of the cervical spine, both when physically examined and when measured using different analysis methods with X-ray images of flexed and extended positions (Paper I & II)
- Signs of dysfunction in the nerve plexus leading to the arm (brachial plexus) (Paper I).

In a questionnaire answered by 1,063 people with minor head or neck injuries 1-3 years after the accident, the following points were reported:

- Chronic headaches and other PCS-symptoms more common after whiplash type neck injuries than after minor head injuries, mostly concussion (Paper V)
- Chronic neck related complaints were unexpectedly common after a pure head injury (Paper V)
- Higher prevalence of both PCS and neck related chronic complaints compared to unselected populations (Paper V).

In a group of traffic accident victims with fatal head injuries:

- Cervical spine injuries occurred frequently; in particular facet joint damage, uncovertebral injuries, and disk ruptures – both multiple and isolated (Paper VI). The majority of these injuries could not be detected, neither during a routine autopsy nor via examining high-quality X-rays (Paper VI).

The results indicate the existence of common biomedical mechanisms behind the development of chronic post-traumatic syndrome after minor head and neck injuries. Common to all of the results was that they are not easily detected by routine examinations, and not by the most commonly used research methods. You have to take a detailed anamnesis, and to perform an extended physical examination – including a nerve tension test. You have to specifically test the oculomotor...
function, and to make a detailed analysis of the functional X-ray images, and you must do an extended pathoanatomical analysis of the cervical spine, to make these results become apparent.

The same can be said for the different gender patterns that arose in most of the studies. It is only after a detailed study of the casualty register and emergency journals that one can discern the differences:

- When compared to statistics concerning men, women more often sustained minor head and neck injuries as passengers and as pedestrians and in collisions from the back or side. Compared to women men were more likely to sustain these types of injuries as the drivers of automobiles involved in frontal collisions and single vehicle accidents (Paper IV).

- Similar differences can be discerned even in non-traffic related accidents: Females were injured in falls during individual sports, such as horse riding and gymnastics, and in the home or while out walking. Males collided with other males or with objects during team sports, such as ice-hockey and soccer, at work, and during leisure activities, the latter often with alcohol involved (Paper IV).

- A recurrent gender pattern in these studies was that women dominated the group of patients with chronic complaints after these injuries (Paper I – III & V). Women also reported more chronic complaints (Paper I & V) and in the oculomotor study (Paper III) only women displayed signs of serious brainstem dysfunction or injury (four patients of 20).

5.2 Methodological considerations

The overall aim of this paper was to seek biomedical explanations for the severe chronic and incapacitating conditions that may result from whiplash-related injuries. Despite the chosen limitation to the field of biomedicine, the problem area is both multifaceted and – of necessity – cross-disciplinary. Additionally, as a consequence of the aims chosen, the focus, selection, and methodology for each section of the study vary, which results in a relatively comprehensive methodological discussion.

From a methodological point of view, the first three clinical studies can be grouped together; this as well applies to studies IV and V. The case report (Paper VII) can be considered a link between the studies, as it summarizes the most important findings from Paper I, II, III, and VI in the thesis.

The clinical study is characterized by the practical interest behind the chosen topic – an interest derived from experience and the potential for increased knowledge about important and relevant clinical phenomena worth studying. This also leads to particular difficulties in comparison to experimental and non-patient related studies, as reality is so multi-faceted that the conditions for the study can be difficult to define in order to obtain clear and valid results. Double-blind, randomized prospective studies of large groups of patients with matching controls, are Utopian ideas. This is at least the case in the area that I have chosen to study – patients with chronic, subjective complaints after injuries that are most often hid-
den even when they are most acute. Furthermore, the physiological and psychological mechanisms behind the complaints are, on the whole, unknown, complex, and multi-faceted. The problems related to finding a method suitable for my purposes are discussed in section 1.6. It was quite a challenge trying to find perspectives and methods that could reflect the complexity as well as the whole and to attempt to integrate quantitative methods, well accepted within medical science, with qualitative methods, which are often used within psychology and social science. The different methods provide answers to different questions and integrated or combined, they can provide us with clearer understanding and better explanations of complex phenomena (Mays & Pope 1996).

This thesis is descriptive. Control groups are not included, with the exception of the oculomotor study (Paper III).

Two of the studies are based on the entire material (Paper IV and VI) and reference populations were used in Paper V in order to compare symptom reporting. The patients in the clinical studies (I–III) were selected consecutively according to predefined inclusion and exclusion criteria.

The thesis actually resulted in generating further hypotheses, rather than proving or rejecting any original hypotheses. Thereby it might lay a foundation for other, prospective, more controlled studies. The case report provides an example of how one can use qualitative methods to describe and analyze a phenomenon by deepening one’s understanding instead of making generalizations. So, the case report, as well, contributes to research by generating hypotheses for later trials.

This thesis comprises examples of the various types of qualitative triangulation that are used for integrating different methods within, among other fields, family practice research (Denzin 1990, Lunde & Mainz 1993). Such triangulation can be performed when one uses:
1. Different methods, for example, quantitative and qualitative methods, in order to obtain answers to or to invoke new questions;
2. Different information sources, patient journals and questionnaires, for example, in order to being able to connect different perspectives and thereby gain a more well-rounded picture of reality;
3. Several observers who analyze the same thing, which can provide cross-disciplinary perspectives and greater opportunities for seeing the whole;
4. Different theoretical perspectives for analyzing data. Within biomedicine and philosophy, e.g., “one wears different glasses” (Lunde & Mainz 1993).

5.2.1 The clinical studies
In Paper I and II, physical examination methods were used, the validity and reliability of which are more difficult to determine than, for example, laboratory tests. There are many factors that come into play when one is to subjectively judge, for example, sensitivity to palpation, muscle tone, range of movement, or reaction to pain during various tests. Much reliance is placed on the levels of skill and experience held by the individual examiner, but also on the interplay between the examiner and the examinee, and the expectations of both in regards to the findings and results. This is a clinical process that is performed by many and the skill of which
can be termed “tacit knowledge” (Polanyi 1983, Josefsson 1988). In one study (Kaltenborn & Lindahl 1969), the inter-reliability of experienced examiners skilled in orthopaedic medicine was tested when they performed mobility examinations on individual vertebrae. The results were considered very good. The results of the physical examination in Paper II were based, among other things, on this type of examination of the segmental mobility of the vertebrae. One of the examiners in our study, JH, is extremely skilled, the other, GB, is quite skilled in manual techniques.

In the presentation of physical findings, the segments $C_0/C_1–C_2/C_3$, $C_3/C_4–C_5/C_6$, and $C_5/C_6–C_7/T_1$ were combined, which increased the ability to reproduce the examinations. In order to judge the segmental mobility of the vertebral column, relatively extensive skills in orthopaedic medicine and much examination technique experience is certainly required (Cyriax 1982, Maitland 1986). Judging the regional mobility of cervical vertebrae, however, is based on the simple biomedical principles for vertebrae mobility (Lewit 1985, Dvorak & Dvorak 1988) and requires far less training. This type of regional diagnostics of the cervical vertebrae mobility can be practiced, therefore, by every general practitioner. The demand for such diagnostic skill (Brodin 1986) is reflected, among other things, in the interest shown during recent decades for courses in orthopaedic medicine for general practitioners.

The reliability of the physical examination results is also strengthened by the good level of agreement with the more objective X-ray examination (Paper II). However, interpreting X-ray images also has subjective moments, where the diagnosis from the same image will vary between examiners (Lilienfeld & Kordan 1966), and quite possibly even between examinations by the same individual (Archer et al 1966).

Measurement of the X-ray images was also performed manually by one person. However, the actual values used were averages from a number of repeated measurements (2-4 times) in order to reduce the margin of error. Dvorak and his colleagues (1988) tested the margins of error created by two independent examiners who measured the rotation angle of each segment using the same measuring technique applied in these studies. They found no statistically significant differences between the results. In another study (Dvorak et al 1991), the difference in margin of error between the different examiners was less than one degree for the rotation angle (RX) and approximately 0.3 mm for the translation measurement (AZ), see Figure10.

5.2.2 The epidemiological studies
In addition to the size of the study populations, two important conditions affect the reliability of the results of the epidemiological studies (Paper IV and V) – partly the accident registers’ coverage and partly any relevant systematic differences between answering and non-answering groups in the questionnaire study. As for the accident registers, control studies in Umeå (Björnstig, personal communication) have shown that approximately 7%, at most 10%, of accident related
injuries are not entered into the register in the emergency room. This high coverage rate can be explained in part by the fact that general practitioners in Umeå (and Skellefteå) health care district spend their on duties in the emergency room, and in part because all patients with injuries, aside from the most minor, are referred to the emergency room. Furthermore, it is quite common for Umeå’s inhabitants to visit the emergency room after accidents involving personal injury, especially in the cases of head injuries and injuries resulting from road accidents. Using this data, one can assume that approximately 90% of all head and neck injuries are noted in the register.

The differences between those who answered the questionnaire and those who did not, require special considerations. The non-responding group was relatively large (28%) and predominantly male, which is common (Papageorgiou et al. 1995). A drop-out analysis was, therefore, necessary and showed that females and those with neck injury symptoms related to their accidents dominated the responding group. The shorter questionnaire with questions about chronic complaints, and the calculated hypothetical minimum and maximum results, based on that questionnaire, showed that a higher percentage of answered questionnaires could even show more marked differences, between the genders, and between the different injury types in the main study (Paper V, Q1).

It has been shown in a large cohort study comprising only men that those who did not answer a questionnaire were more ill and had more psychosocial problems than those who had answered (Silverbäg–Carlsson et al 1987). On the other hand, however, one might assume that those who suffer from pain and other subjective symptoms are more likely to answer questions if these concern their specific complaints (Ahlbom & Norell 1981). Furthermore the main reason put forth for returning a blank questionnaire was that the individual currently had none of the problems or complaints we asked about, which supports the latter assumption. Including all of the 150 who sent back the questionnaire but did not answer the question, with the assumption that they did not suffer from any of the specific symptoms we were interested in, was seen by us as a method of avoiding an overestimation of the number of people suffering from chronic complaints. It is, therefore, reasonable to assume that the drop-outs did not affect the results of the study to any significant degree. The results of the small study (Q2) also agreed well with the main study (Q1).

5.3. Comparison with other studies

Since the middle of the 1980s, the proportion of whiplash-related traffic injuries has increased in all Western insurance claims, having increased from a fraction of personal injuries leading to compensation to more than 50% today (Quebec Task Force 1995a). Additionally, the number of published articles about the subject has increased from a few to several hundred a year (Quebec Task Force 1995b). The large number of articles, the multi-faceted set of symptoms, and the multitude of backgrounds to the symptoms led me to the decision to attempt to perform a
limited and problem-based classification of the extensive research area that affects the results of this paper. The problem areas that I chose to focus on are:

1. Similarities and differences in WAD and PCS, “upper” cervical syndrome, and possible causes behind these
2. WAD and TOS, “lower” cervical syndrome, and possible causes behind these
3. Cervical spine segmental mobility dysfunction
4. Cervical spine segmental mobility dysfunction as a biomedical explanatory model for development of chronic post-traumatic symptoms – (the root of all evil?)
5. Epidemiology
6. Gender differences

5.3.1 Similarities and differences in WAD and PCS, “upper” cervical syndrome

The patients in the clinical studies comprised a small selected group that had such severe chronic complaints that they were sent from one of the four most Northern Swedish counties to the regional hospital for investigation, diagnosis, and judgement. The wide variety of symptoms that each of these patients developed after whiplash injuries have been described by other researchers (Braaf & Rosner 1958, Jackson 1977, Evans 1992b, Barnsley et al 1994). In the German literature on this topic, a dividing line is often drawn between “upper” (zerviko-occipitale or zerviko-kraniale) and “lower” (zerviko-brachiale) cervical syndrome (Decher 1969, Zenner 1987). Most of the patients (Paper I – III) had pronounced PCS-symptoms including headaches and dizziness. Many patients also had other otoneurological symptoms and vision-related problems. All in all, they displayed a set of symptoms consistent with “upper” cervical syndrome.

The debate as to whether brain or cervical spine injury is the cause of this upper cervical syndrome (or “post-traumatic neurosis”) has continued since at least the end of the 1800s (Trimble 1981, Keller & Chappell 1996). In terms of definition, concussion can be sustained from a whiplash mechanism, but injury to the cervical spine can also be caused by the forces acting on the patient’s head (Evans 1992a,b, Barnsley et al 1994). Erichsen (1866) described the symptoms as “railway spine”, which he attributed to a “spinal concussion”. The condition is described as having an insidious development of symptoms including back pain, neurological problems in the arms and legs, ataxia, vision problems, confusion, insomnia, headaches, irritability, and extreme fatigue (Erichsen 1882). Similar symptoms had previously been described as the consequences of war injuries (Lidell 1864) and were even then attributed to “spinal concussion”. It was noted then that even the most severe cervical spine injuries did not automatically lead to the most severe chronic consequences (if the patient survived). Fractures, for example, could heal without problem, while a post-traumatic syndrome could develop after milder trauma, especially if the body was hit from behind (Erichsen 1882). A century later, Clay et al (1987) showed that the mildest injuries (AIS 1), sustained to the locomotive system and especially those caused by whiplash injuries, often lead to long-term invalidity after an automobile accident. Their hypothetical explanation was that the healing ability of certain joint structures,
such as cartilage and joint capsules, ligaments, and disks is less than that of those in the skeleton and certain internal organs.

Upper cervical syndrome has been characterized by several paradoxes. Among them are the discrepancy between the number of subjective symptoms and no or few objective findings, the risk for long-term invalidity after trivial injuries, and the delayed development of symptoms. Partly because of specialization within medicine, these paradoxes have led to a dichotomy in the search for the causes. Studies within this area have come to cover either head injuries or neck injuries, and either somatic or psychological causes of the symptoms. Even today, the importance of distinguishing between these injuries is emphasized (Quebec Task Force 1995b, Mayou & Radanov 1996). However, in two other relevant review articles about whiplash injuries (Evans 1992b, Barnsley et al 1994), the difficulties of such a division were discussed. Also, from a general medical perspective there are advantages in not dividing complaints according to organs, but rather striving to reach a problem-based perspective when diagnosing.

Recent studies have also shown – objectively – that the symptoms of upper cervical syndrome are of a similar nature whether the cause is a whiplash or head injury (Weiss et al 1991, Ettlin et al 1992, Radanov & Dvorak 1996, Otte et al 1996).

The search for causes of the otoneurological symptoms has again begun to focus on the cervical spine. Paper III, the oculomotor study, was conducted in order to find an explanation for the symptoms reported by individuals that sustained neck injuries without any element of head injury. Before we began the study in 1986, very few studies had been conducted in the area (Maeda 1979, Maeda & Ishii 1984). Since then, several reports have appeared that support our findings (Oosterveld et al 1991, Ettlin et al 1992, Hildingsson et al 1993). More recently, Kortschot (1995) examined 552 consecutively selected patients that had been hit from behind in traffic accidents and had sustained whiplash injury symptoms. There was a high frequency of oculomotor dysfunctions, but not as high as in our small group of patients with pronounced chronic symptoms. This discrepancy reinforces the suspicion that brainstem dysfunction is mostly connected to severe symptoms, but it is not necessarily the cause of them. Further support that this is the case was given in a prospective study (Hildingsson 1993) where oculomotor dysfunctions of the same type as in our study (Paper III) were seen in a number of whiplash patients only after some time had elapsed after the injury.

A number of experimental studies have aimed to find the causes of the symptoms in diffuse axonal injuries in the brainstem (Ommaya et al 1968, Adams et al 1982, Jane et al 1985). Four of the patients in our symptomatic group (paper III) had very pronounced symptoms such that brainstem damage could be suspected. All four were women that had sustained their neck injuries during high speed accidents, and all four had immediate symptoms of the injury, consistent with lesions in both the cervical spine and the brainstem. The set of chronic symptoms did not vary to any significant degree between these four and the others in the group. This would support the idea that brainstem dysfunction is more commonly
a secondary and not a primary consequence of injury, further strengthening the suspicion that brainstem dysfunction is connected to severe symptoms, but is usually not the cause of them.


Henriksson and Pyykkö (1984) and Karlberg (1995) describe, in a clear manner, the complicated eye movements and balance functions controlled by the brainstem. In Karlberg’s thesis (1995), the brainstem’s vital importance for maintaining balance, bodily positioning, and coordination is also shown.

All coordination of bodily movements, including movements of the eyes and the chewing/swallowing system, are integrated in the brainstem and rest on three important pillars. I.e., signals from the balance organ in the inner ear, impressions from vision, and signals from the body’s joint and muscle sense, proprioception, which includes skin receptors, mainly those in the soles of the feet. The entire system for maintaining equilibrium and coordinated movements is based on a continuous bi-directional flow of impulses and continual automatic corrections and fine adjustment via muscle activity initiated by this system, all performed by an extremely complex network of feedback mechanisms. The proprioceptive system is very sensitive; i.e., it is enough, for example, to even consider changing your line of sight to activate the neck muscles via this system. As a result of this, only minute disturbances are required to affect the system, and a lack of activation alone can be enough to disturb the function and to cause dysfunction. Such lack of activation could result from pain inhibition or some other form of immobilization.

In addition, there are the different signal systems within our nervous systems. Neurotransmitters, endorphins, hormones, immunity substances, waste products from muscle activity and other processes, the autonomous nervous system, etc. are all integrated, cooperative, and effectual in complex patterns that are difficult to comprehend. The sympathetic nervous system, which supports many important functions, is located on the anterior side of the vertebral column. It communicates extensively both with the central nervous system, and all muscular activity throughout the body, and is considered – due to its location – to be sensitive to direct injuries resulting from overextension, but also from mechanical irritation from scars after injury (Braaf & Rosner 1958, Jackson 1977, Breig 1978, Butler 1991). Another connection between cervical spine injuries and brainstem symptoms maybe the vertebral artery, which can be effected directly, mechanically, and indirectly via the sympathetic nervous system (Herrschaft 1971, Decher 1969, Jackson 1977).

All these references support, in one way or another, the theory that both symptoms and signs of dysfunction in the brainstem can originate from the neck receptors, which is consistent with the results from our otoneurological study (Paper III).
5.3.2 WAD and TOS, lower cervical syndrome, possible causes

Most studies of the causes of chronic symptoms after whiplash injuries concentrate on the classic neck symptoms (painful/stiff neck, pain and numbness in shoulders/arms), including or excluding headaches (Jónsson et al 1994, Pettersson et al 1994, Pettersson et al 1995, Barnsley et al 1995). There are, in general, no diagnostic problems in cases where the symptoms spread so that they follow a dermatome down the nerve roots and where equivalent structural, radiological changes explaining the symptoms can be found in the cervical spine, for example, a slipped disk at the “right” level. In some cases, the course of treatment is also obvious and provides the desired effects. Much more common and problematic, however, is that the symptoms are of a more diffuse and often varying character. The term “lower cervical syndrome” or TOS covers these symptoms.

Most of the patients in Paper I, and the patient in the case study (Paper VII) described such diffuse symptoms as pronounced; and half of those in Paper I, and the patient in Paper VII presented positive nerve tension tests on one side or bilaterally. The brachial plexus could be the source of TOS-symptoms in these patients. As there are seldom any signs of direct neurological damage among patients with TOS, there has been a concentrated effort directed toward a possible secondary injury mechanism. Surgical exploration of the plexus has shown fibrosis, i.e. scar tissue, in and around the nerves (Sanders et al 1979, Nyström 1986, Dellon 1993). In their work, Breig (1978), Elvey (1986) and Butler (1991) have shown the nervous system’s sensitivity to adverse mechanical tension, wear, and compression. The brachial plexus appears to be a structure that is especially open to such fibrotic scar effects following various types of trauma, such as whiplash injury.

The so called “double crush” phenomenon, where an injury to one part of a peripheral nerve can produce alterations in other parts of the nerve, is one such mechanism, and its effect upon the brachial plexus has been described (Upton & McComas 1973, Butler 1991). A general and possibly individual tendency to fibrosis around nerve roots and the brachial plexus is another possible causal mechanism (Frykholm 1951). The area around the plexus is intentionally avoided, for example, during angiography, as one knows from experience that even slight hemorrhaging (bleeding) there can lead to symptom-producing fibrosis (Liliequist 1986, personal communication). One important observation is that in daily work in forensic pathology, one encounters victims of traffic accidents, especially those that survived a few days after the accident, displaying hemorrhaging on the anterior side of the cervical spine that sinks down into the loose tissues surrounding the brachial plexus. In our pathoanatomical study (Paper VI), two such cases were seen, one single-sided and one bilateral.

The patient in the case report (Paper VII) had typical left-side TOS-symptoms, presented a positive nerve tension test on the same side, and had pronounced fibrosis in the left brachial plexus in comparison to the right side. Additionally, he displayed signs of segmental hypermobility/dysfunction in the middle cervical spine during physical testing, a dysfunctional pattern on the functional diagram.
from the analysis of the flexion/extension X-ray images, and postmortem patho-anatomical alterations at the C5/C6 level. All these alterations are consistent with post-traumatic development. An initial injury to joint structures in the middle cervical spine would be able to explain, through the mechanisms described above, both the alterations and the consequent symptoms.

Myelography (case report, Paper VII) also showed deformation of the axillary pouch (root pocket, root sleeve) on the right-hand side on the same level without, however, this alteration having any ascertainable clinical relevance (as opposed to the alteration in the brachial plexus, which was found on the same side as the symptoms). Similar root pocket deformations in the lower cervical spine segments were seen in eight of the patients in Study II. There seemed to be no clinical relevance to symptoms in these cases either, but the findings do indicate a common origin, through some traumatic mechanism, possibly so called adverse mechanical tension (Breig 1978, Butler 1991).

Further anecdotal evidence supporting the theory of fibrosis as the cause of TOS was found in the patient group in Paper I, II, and III. Since 1986, five of these patients have undergone surgery to the brachial plexus, all involving neurolysis/fibrolysis (loosening of scar tissue), and some have even had a scalenectomy. The initial results have been very good for the majority, but long-term effects are still uncertain.

5.3.3 Cervical spine segmental mobility dysfunction
In addition to the signs of dysfunction in the brainstem and in the brachial plexus, the patients in our clinical studies (I – III) also exhibited signs of dysfunction in cervical spine segmental mobility. Segmental instability in the neck has been shown to cause dizziness and disturbed oculomotor function among patients with whiplash injuries (Hinoki 1985). Experiments have also shown that segmental instability can arise as a result of ligament injuries sustained from accelerating forces (Macnab 1971, Penning 1994).

Arthrotic changes in the uncovertebral joints or in the facet joints of the cervical spine have long been a suspected cause of “upper cervical syndrome” (Barré 1926, Lieou 1928, Bärtschi-Rochaix 1949, Lewit 1985, Tamura 1989). From the three topmost neck segments (C1, C2, and C3), the occipital nerves emanate, and communicate pain impulses to and from the neck and head (Poletti 1991, Lord et al 1994, deJong et al 1977, Dieterich et al 1993). Disturbed input from the receptors in these segments to the integration center in the brainstem is considered to affect oculomotor function and other brainstem functions (Hikosaka & Maeda 1973, Hinoki 1985, Karlberg et al 1991, Poletti 1991). The facet joint nerve that originates from the C2/C3 segment has an especially important function in proprioceptive integration in the brainstem. If one anaesthetizes this nerve on both sides simultaneously, the patient suffers from dizziness and/or ataxia (deJong et al 1977, Dieterich et al 1993).

Tamura (1989) showed a connection between arthrotic changes at this level (C2/C3) and pronounced cranial symptoms (upper cervical syndrome) in whiplash
victims. In recent years, the research groups based around Bogduk in Australia and Aprill in the USA have been able to show that the facet joints from C2 and downwards are of great importance in the development and continuation of pain after whiplash injuries (Keith 1986, Aprill & Bogduk 1992, Barnsley et al 1993, Barnsley et al 1995, Dwyer et al 1990, Aprill et al 1990, Lord et al 1996). The patients in our clinical study showed consistent patterns of dysfunction in segmental mobility in the cervical spine, during both physical examination and different analyses of the functional X-rays (Paper II). A reasonable hypothesis is that these patients sustained injuries to the joint structures in the cervical spine and that, for one or more reasons, these injuries have not healed properly and full function has not been restored. This hypothesis would explain the patients’ chronic neck and head pain in terms of the spreading, character, and resistance to treatment of the pain (Aprill & Bogduk 1992, Barnsley et al 1993, Barnsley et al 1995, Dwyer et al 1990, Aprill et al 1990, Lord et al 1996). It would also explain the disturbed segmental mobility patterns in the cervical spine (Lewit 1985, Dvorak 1993) and the subjective symptoms resulting from disturbed brainstem function (Hikosaka & Maeda 1973, Hinoki 1985, Karlberg et al 1991). Furthermore, this hypothesis would explain the fluctuating and sometimes even reversible or relapsing character of the symptoms. Additional support for this theory is provided by Karlberg’s thesis (1995). In one of his studies, it could be shown that both pain and moderate disturbances in the balance function were secondary to pressure on the nerves from a slipped disk or spondylosis of the cervical spine (Karlberg 1995). Even in our group of patients, oculomotor function was normalized in some patients after anterior fusion, but the matter still needs to be systematically researched.

In our case study (Paper VII), the patient showed signs of brainstem dysfunction and disabling symptoms of the PCS type, which could be explained by a cervical spine injury with disturbed afferent impulses from the joint structures.

In conclusion, there is support for the interpretation of the results of our clinical studies showing that upper cervical syndrome, including the most common symptoms of brainstem dysfunction, headaches, dizziness, etc., originates from a post-traumatic dysfunction of the cervical spine associated with segmental mobility dysfunction. Whether this dysfunction is caused by injuries to the facet joints, disks, the uncovertebral joints, the sympathetic nervous system, or some other structure in the cervical spine is, however, still unclear.

5.3.4 Segmental dysfunction – as a biomedical explanatory model for development of all chronic post-traumatic symptoms – the root of all evil?

The changes in the joints and the signs of segmental dysfunction in the cervical spine seen in upper cervical syndrome and which were discussed above are also relevant to pain and other symptoms experienced further down in the cervical spine. These changes also ought to be viewed as relevant general explanatory models for the pain and dysfunction experienced by many WAD patients in other parts of the back and in other parts of the locomotive apparatus. Breig (1978) and Butler (1991) both emphasize that the entire nervous system is a single unit; every
separate nerve has mechanical connections with other parts of the nervous system, sometimes with nerves in distant parts of the body, rather like the branches of a tree. Using theories about the nervous system’s function that have been put forward by Breig (1978) and Butler (1991), among others, the delayed development of symptoms in *post-traumatic cervical syndrome*, along with their multi-faceted, fluctuating, and varying character, can be logically explained. Different models of *myofascial pain*, *referred pain*, and *trigger point* pain (Travell & Simons 1983), as well as ligament pain (Lewit 1985), pain from peripheral nerve entrapment (Poletti 1991, Butler 1991), and segmental pain from joint structures in the cervical spine (Barnsley et al 1995, Wallis et al 1996), can also be applied to these patients. This can also be done in a similar fashion to the experimental studies of the connections between neuromuscular functions and pain that are currently being conducted in Umeå, e.g., by Kinnman (1989), Djupsjöbacka (1994), and Bergenheim (1995). In this context, there are also interesting results concerning the connection between neck receptors, head posturing, and the *temporomandibular* and masticatory functions (Rocabado 1982, Rocabado 1983, Kirveskari & Alanen 1984, Kirveskari et al 1988, Zafar et al 1995).

In Paper II, we analyzed segmental dysfunction in the cervical spine, expressed as *hypo- or hypermobility*. The consistent patterns that appeared during both detailed clinical, physical examination and detailed analysis of the *functional X-ray* images form the foundation of the theories concerning *blockages* and relative instability, respectively, that were put forward by, for example, Lewit (1985) and Dvorak (1993). Whether there is primarily some form of ligament damage in the middle cervical spine (*C3/C4 – C5/6*) or not, it seems that relative *hypermobility* develops after some time. According to Lewit’s theories (1985), the restricted mobility – *segmental hypomobility* – at key levels, i.e., the crossover from the base of the skull to the cervical spine and down to *C2/C3* and the crossover from the cervical spine to the thoracic spine are important to this development. In many of our cases, *hypomobility* in these areas can be recorded as a *blockage* of the segment. Such a blockage is considered to arise reflectively through minor traumas or because of pain. Such restricted mobility alone, often cause pain, but it is easy to treat using mobilization techniques (Cyriax 1982, Maitland 1986). According to Lewit (1985), they can produce secondary effects, through an increased risk of *hypermobility* developing in surrounding segments. If this is the case, it would explain in part why dysfunction in the form of segmental *hypermobility* regularly appears at the *C3/C4* and/or *C4/C5* levels in our patients. That it is genuinely a matter of *hypermobility* and/or disk injuries at these levels is partly confirmed by the fact that 12 of the 22 patients (in Study I – II) have undergone *anterior fusion* surgery due to disk injuries and/or instability at these levels since the study was conducted.

According to Lewit (1985), Rahlmann (1987), and others, the *meniscoids* are important both with respects to normal joint play and to *proprioceptive* function in the *facet* joints, and to the formation of *blockages*. In our *pathoanatomical* study (Paper VI), there was a very high frequency of *uncovertebral* and *facet* joint
injuries among traffic fatalities. In many facet joint injury cases, hemorrhaging was reported in the meniscoids. The same findings were observed by Schönström et al (1993) and Taylor (personal communication 1996) in their studies of traffic fatalities. According to Taylor, hemorrhaging was especially common in the meniscoids in the C1/C2 segment, where they are very large and well supplied with blood vessels and nerves.

In our case report (Paper VII), where we pathoanatomically examined the cervical spine 12 years after the injury was sustained, we saw pronounced fibrosis in one of the meniscoids at the C5/C6 level (see the image 3D, Appendix, p 147). At the same level and the level below, pronounced hypomobility was observed (according to the functional diagram based on the analysis of the flexion/extension images). The level above (C4/C5), however, showed signs of so-called relative hypermobility (Fig 13). If the meniscoids are really as important for mobility and proprioception as can be expected, then the damage at the C5/C6 level could explain, at least partly, the development of dysfunction in the patient’s cervical spine. If this is the case, then the segmental alterations, including the degenerative constriction of the nerve root sleeve found on the right-hand side and the arm symptoms on the left-hand side, are not contradictory. On the one hand side, such constrictions do not necessarily lead to symptoms (Friedenberg et al 1960, Lawrence 1969), but can be detected by chance. On the other hand, dysfunction of the facet joint on one side, might disturb the entire segment and thereby the whole spine, due to biomechanical reasons. Even if the degenerative alterations do not have any clinical relevance, in this case they provide support, together with the other segmental alterations, to the theory of a traumatic origin, primarily through their localization (Friedenberg et al 1960, Lawrence 1969).

Combining these findings, we can see that the cause of the patient’s pain, and other TOS symptoms, is most likely not confined to a single structure, or at least not to the same structure in all sufferers. Most theories and treatments today focus on dysfunctional conditions of the musculoskeletal system apparatus and the coordinative joint and muscle interactions. A detailed examination, performed in accordance with principles of orthopaedic medicine, including Elvey’s nerve tension test and detailed analysis of the functional X-ray images, provides a simple aid for diagnosing dysfunctional conditions. Hopefully, if such testing is performed at an early stage and followed by treatment of the symptomatic blockages in the upper and lower parts of the cervical spine, then development of symptomatic hypermobility may be checked, as this latter condition is considerably more difficult to treat after it is well developed. In those situations where a WAD patient dies and an atopsy is to be carried through, and particularly in those cases where a chronically dysfunctional and disabling condition is well developed after cervical spine injury, and where comprehensive examinations have been conducted without leading to effective treatment, it would be of value to examine the cervical spine and nervous system in more detail than normally is done during autopsies.
5.3.5 Epidemiological results

In Sweden, attention was first drawn to whiplash injuries with the publication of Nygren’s thesis on internal automobile safety (Nygren 1984). He was able to show that approximately 10% of all personal injuries sustained in cars and resulting in a medical disability of at least 10% were caused by neck injuries received at a rear-end collision. This was a notably high figure, as these types of injury had previously been considered of little importance. In the casualty register, they seldom merited a higher rating than AIS = 1, that is, the most minor injury type.

The incidence of whiplash injuries varies greatly between different studies because of variations in injury definition and patient selection, social and cultural differences, different traffic and insurance systems, etc. Four comprehensive review articles about whiplash injuries published during the 1990s (Evans 1992b, Barnsley et al 1994, Quebec Task Force 1995b, Mayou & Radanov 1996) all state incidence values between one and four per thousand inhabitants per year. Schutt and Dohan (1968) calculated the incidence among the special risk population comprising adult female car drivers and passengers and produced a value of 14.5 per thousand and year. According to the latest report from the department for traffic injury prevention at the Karolinska Institute in Stockholm (Nygren, personal communication 8-31-1996), each year in Sweden, approximately 16,000 people report symptoms of an acute whiplash injury, which would indicate an incidence value of approximately 2/1000. Furthermore, whiplash is noted as the type of injury with the highest increasing frequency and as the most common cause of permanent disability after a road accident.

The incidence values for minor head injuries also vary, for the same reasons as whiplash injuries, but the most reliable data provides a figure of 1.3 /1000/year (Kraus & Nourjah 1989).

The incidence figures that we obtained (Paper IV) are high in comparison to the above values. One explanation could be that we adjusted the values for age and gender and we excluded age groups where neck injuries are uncommon (but head injuries are very common). Another explanation could be that we included anyone who showed minor neck or head injury symptoms. Register studies are normally based on diagnostic codes, which leads to the risk of excluding many patients with minor injuries and concomitant injuries. The good coverage provided by the casualty register could also have contributed to our high figures.

The dominant accident type in most whiplash injury studies is rear-end collision, but the proportion of other traffic accident types resulting in whiplash type neck injuries has increased since the middle of the 1980s. There is certain evidence that this increase, as is the case for the increase in whiplash injuries from rear-end collisions, is associated with the increased use of seatbelts (Deans et al 1987, Otremski et al 1989). Laws regulating the use of seatbelts have been introduced in many West European countries and in many states in the USA during the past twenty years. In those cases where the effect of the new laws on accident patterns has been studied, a clear tendency for an increased proportion of neck injuries in traffic accidents has been observed (Salmi et al 1989, Galasko et al...
The increase in neck injuries as a proportion of personal injuries depends, at least partly, on a simultaneous decrease in head and torso injuries. This reduction has been seen in all countries that have introduced laws requiring the wearing of seatbelts. The introduction of airbags in many automobiles has also reduced the number of serious head and torso injuries (Huelke et al. 1992), but no studies have yet been conducted regarding the effect of airbags on the incidence of neck injury.

During the same period that whiplash injuries increased in both absolute and relative terms, the number of head injuries in traffic decreased, primarily among moderate to severe injuries. The prevalence figures for chronic WAD and PCS conditions are difficult to compare, just as incidence figures are (Evans 1992a, Evans 1992b). Both conditions are characterized by subjective complaints that, on an individual symptom basis, are relatively common among the population as a whole, without necessarily having been preceded by an injury (Evans 1992a, Evans 1992b). There is evidence, however, that the symptoms of post-traumatic syndrome after both neck and minor head injuries are greater in number and more troubling than among the general population (Olsson et al. 1990, Ettlin et al. 1992, Radanov et al. 1993, Barrett et al. 1994, Bohnen et al. 1994, Barrett et al. 1995).

The proportion of chronic complaints reported in the questionnaire study (Paper V) indicates a high prevalence of chronic post-traumatic disorders after acceleration/deceleration forces on the neck and head. The risk of developing such a condition was also significantly higher after neck than head injuries (AIS ≤2). This increased risk was associated with the female gender, which was the most consistent risk factor evident for the development of chronic complaints after injury of the types relevant to our study.

5.3.6 Gender differences – Do women sustain neck injuries easier than men do? Or do they get lighter neck injuries? Or do they even get neck injuries easier than they get men? (This is a Swedish play with words that is lost in the English language)

The patients in the clinical studies (Paper I – III) comprised a small, selected group on referral from various parts of Northern Sweden (see 3.1.) for the investigation of severe and chronic symptoms that arose after whiplash type neck injuries. The majority had been injured in traffic accidents, 40% had been hit from behind, the average age at the time of the accident was 33 years, and the mean age at the time of the investigation was 38 years. Considering this basic epidemiological data, this group was representative – despite the selection process – of the chronic, whiplash-related disorder that has been described in comparative studies over the past 40 years (Gay & Abbott 1953, Hohl 1974, Norris & Watt 1983, Radanov et al. 1994, Quebec Task Force 1995a). This data are also consistent with the results of Paper IV and V in this thesis, which were based on considerably larger patient populations and also covered minor injuries to the head.

In our small group of patients (I – III), two thirds were female – making it comparable with the cohort study from Quebec (Quebec Task Force 1995a). The Quebec cohort study included a total of 4,757 people that had received some form
of compensation from Canada’s only insurance company, SAAQ, for whiplash related injuries sustained in automobile accidents during 1987, and the women outnumbered the men by two-to-one.

The finding that women dominate the group with chronic complaints after minor neck injuries would appear to be reliable. There is most likely a many-fold explanation to this sex difference, and it is probably not purely biomedical. Of course, the same can also be said about the fact that men dominate the statistics for all severe and fatal accidents. However, the connection between women and neck injuries provides food for thought. Can this connection be a result of physionomy, hormones, or psychosocial factors? Or perhaps it is due to gender differences in behavior in traffic, at work, in the home, or as patients? And what importance has the gender of the other driver in the collision? Why are men more often injured when involved in frontal collisions or driving off the road? Is it difficult to answer these questions without more detailed registration of accident data.

Is the difference due to women driving lighter automobiles that entail a greater risk of being injured in an accident (Nygren 1984)? Is it because women let their partners drive and the risk is greater in the passenger seat, as one is less prepared in the case of an accident? What importance does the design of automobile seats, neck supports, and seatbelts have (Svensson 1993)? Is the fact that women are more law abiding in the use of seatbelts important (Lacko & Nilsson 1988)?

Some results in the register study (IV) indicated that women were more susceptible to injuries, in relation to men, when the collision force came from the side or the rear, that is, during accidents at junctions and in urban areas. Is this dependent on different levels of exposure? Men and women usually have different reasons for driving and women most often drive to and from work, the kindergarten, and the stores (Gregersen & Berg 1994). What effect does this have? Do women drive differently from men, in the same way that they seem to lead different lifestyles (Gregersen & Berg 1994)? What importance does the gender difference in willingness to take risks in traffic have (Koneční et al 1976, Evans & Wasielewski 1983, Groeger & Brown 1989, Schulze 1990, Rajalin 1994, Cooper et al 1995, Massie et al 1995)? Are women injured in traffic because young men think that it is fun to drive around in their automobiles at high speed and because they think that women drive too carefully (Gregersen & Berg 1994)? Are women drivers hit from behind by male drivers because men assume that everyone drives the same way as they do and accelerate when the traffic light is about to change to red, despite a distance of 60 yards to the stop line (Koneční et al 1976)? Are traffic systems designed by and for men (and automobiles) without consideration for the needs of children, the elderly, and women or the conditions for cyclists and pedestrians? If this is the case, what effects, if any, does this have on our topic?

Hakamies-Blomqvist (1994) showed that elderly and female drivers behave quite similarly in certain respects that are important for accident statistics. Are female (and elderly) drivers less aware because they have too much else to think about? Are men less aware due to deficiencies in parallel thought processes or simultaneous capacity?
Are women more aware of pain? Do they suffer more from pain than men do? Are they more affected by an injury that affects the ability for parallel thought processes simply because they have an ability for parallel thought processes that can be affected? What importance does the fact that many women hold two or three different jobs have? Is it significant that women – as a group – are paid less than men are? Is it significant that they receive less rehabilitation after an accident than men do? Is it significant that they are seldom given time to rest, exercise, or receive treatment? Is it significant that their pains and illnesses have always been considered psychosomatic? Is it significant that a woman who is plagued by chronic pain is often diagnosed as “in the menopause” or “somatizing” (that is, projecting psychological or personal problems onto her body)?

How does an individual feel when plagued by chronic pains that cannot be seen? How does it feel not to be seen by a doctor personally or to be treated as a difficult patient who does not desire to get better? What is the importance of the fact that women generally have proportionally longer, slimmer, and weaker cervical spines with proportionally longer and, above all else, more narrow spinal canals? Is it also possible that women have more sensitive nervous systems?

The answers to these questions do not exist – yet. Some answers of this sort can not be obtained using epidemiological methods; they require qualitative interview studies in order to learn more about the reality behind the statistics. We see then, that it would not seem possible to find a simple explanation for the gender differences. The causes are most likely many/multiple, as are the causes of post-traumatic syndrome in general.
Reflections

‘Omnis festinatio ex parte diaboli est’
(Haste is the work of the Devil)

The title of this thesis has amongst other things aimed to emphasize the many facets of the problems of whiplash related disorders – without making any claim on highlighting all of them. The complexity of the post-traumatic syndrome and the methodological difficulties to study it is as well a type of facet in this problem. The facet joints, inaccessible but sensitive structures which are central cogs in our mechanics of movement and coordination, seemingly represent an important root of evil in the chronic syndrome, and is a motivation to the choice of title of this thesis. An alternate title could have been ‘an evil with many roots’.

Well, what has working with this thesis taught me? Did I get answers to my initial questions? Aside from the fact that I learned something about the conditions for scientific work, I also have certainly learned that things are not always what they seem to be, i.e., what seems simple initially can actually be difficult and complex. The whiplash injury which was an unknown concept for me in the beginning appears now as a metaphor for our society and our time; whiplash related injuries and disorders might be conditions caused by ourselves and our stressed and strained modern way of life.

Omnis festinatio ex parte diaboli est – Haste is the work of the Devil. Haste is probably the most common cause of whiplash injuries. You are standing there calmly (or maybe impatiently) and abiding the law to await your turn for the green light – then Bang! Someone had more haste than you and did not have time to stop. Haste and lack of time in the emergency room do not always permit for proper attention for the one who has been recently injured – maybe the patient is primarily in shock or dazed but lack signs of visible injury. Hurry and stress are often obstacles for receiving proper treatment and for restoring function. When the chronic situation is established it is characterized by constant and destructive stress. One becomes intolerant to stress, physically as well as mentally, and chronic pain as well seems like a constant addition of stress and disrupted sleep; in other words, the batteries never reload. Stress provokes symptoms which in themselves increases stress; stress negatively affects cognitive functions, which tend to further increase the stress, and so on.

The best and often the only treatment that most of ‘my cases’ have experienced, has been when they learned to understand and accept the fact that all stress is bad and devilish for them. Not until then could they deal with their pain, their physical and mental dysfunctions and find a new way of life – not one without symptoms but one with and in spite of them. Some describe that not until they stopped taking pain killers, and instead listened to the warning signals about intensified pain, did
life become bearable. One must learn to stop, take it easy, take a break, and be patient for the body that no longer may tolerate life’s strain and stress as before.

As a physician meeting these patients, we can seldom be the Healer that we and, of course, the patients want. But through increased knowledge combined with empathy we can help guide these patients a little along the way to finding how to help themselves which is often the only help to get. This may be achieved by:

- listening (giving time), thorough examination (orthopaedic medicine), nerve tension tests
- searching for important but invisible roots (function-analysis of X-ray pictures, nerve tension test and other tests, diagnostic blockages, physio-therapeutic test treatments, acrylic splints, etc)
- explaining function, dysfunction, pain and other mechanisms (not underestimating the patients competence, desire and ability),
- offering the help and support for self-help which may be specific for different patients and that which only the individual knows: being put on the sick-list?, adjustment for the place of work and rest?, change of work?, sickness pension?, work part-time?, flexible time?, referral to a specialist? physio-therapist?, Feldenkreis educationalist? rehabilitation programs? psychotherapy support? (show respect and act in accordance with the medical oath: let us be guided by love of mankind, science, reliable experience and not in the least, constantly seeking to extend our knowledge).

Is it possible to minimize accidents and neutralize unequality in society via the traffic system? To adjust the system to children, the elderly and women’s needs and conditions? Instead of as it is now – the motor vehicle traffic is first considered and the unprotected road-user are to adapt to it? How to decrease the stress in traffic and in every day life, at work and school?

Visions for future: Primary prevention. Are cars, including back-rests and head-rests optimally adjusted to women? To the individual? Can the technique be used to influence peoples behaviour? Secondary prevention. Which is the best treatment initially when the injury arises? Wearing or not wearing a collar? The type of collar? How long should it be worn? Rest? Physiotherapy? Mobilization? Training? When? How long? What is sufficient information about the injury? One person can feel good by calming information and encouragement, whereas, someone else may need words of warning and explanation about the seriousness. In this respect research results are lacking or full of contradictions, therefore a good deal of work needs to be done.

As patho-anatomy and patho-physiology behind whiplash injuries and disorders are still obscure the need for research in the following fields is abound:

- Morphology – function – dysfunction of the nervous system (physical and mental).
- Morphology – function – dysfunction of joints, especially facet joints.
- Morphology – function – dysfunction of muscles and proprioception including the chewing system.
Moreover there are needs for research within behavioural science, sociology, biomechanics, medical insurance, etc.

The area which is very much at heart for me is however to deepen our knowledge about what really happens with the individual. What was it that happened to ÅN? Did he have a segmental injury at C5 or C6, perhaps with a concomitant injury of the vertebral artery with the formation of thrombosis and later embolism to the “pica” on one side? Or did he possess vascular anomaly (divergent anatomy) that made him exceptionally sensitive for spasm or mechanical clogging of one of his vertebral arteries? And if that was the case would it have been something that one could have taken care of, prevent symptoms, treat or to compensate? To get some answers to these types of questions we would have needed “single case analysis” for each separate case. Such a case analysis should include a careful clinical investigation perhaps in accord with the principles emphasized in this theses, test treatments may be necessary and as may continued searching for the ‘roots of evil’ that are not conspicuous but surely exist. Roots that become visible only when one is aware of them and knows where to look. Then they may visualize the whole in the small part. Case studies, when multiplied, at the end form a totality through the patterns that have been displayed. From the individual case to the generalisation and then back to the individual along the path of discovery. ÅN was my first case study that enlightened a number of questions. LS (Paper VII) was hopefully not my last. I discovered new patterns and thereby new questions arose. Both have helped me to find new hypotheses, antitheses and to synthesize for once in life (?) – a thesis. All my cases also taught me that

_Haste is the work of the Devil – ‘Omnis festinatio ex parte diaboli est’._
Summary


The original papers on which the thesis is based are published separately in an appendix which can be obtained from the Centre for Musculoskeletal Research, the National Institute for Working Life, Box 7654, SE-907 13 UMEÅ, Sweden, fax +46-90176116.

Head and neck injuries represent a category of particular concern as even in mild cases (AIS 1) the outcome may be chronic disability. Initially, and in the event of chronic posttraumatic disorder, both head and neck injuries are characterized by the same symptoms, and the acceleration/deceleration injury mechanism is also similar. The physiopathogenic mechanisms underlying the development of chronic whiplash-associated disorders (WAD) and chronic post-concussion syndrome (PCS) are still unknown.

The studies upon which this thesis is based were focused on the symptoms and clinical signs of chronic WAD, the epidemiology of minor head and neck injuries, the prevalence of chronic symptoms following such injuries, and cervical injuries in road accident victims with fatal head injuries.

In a selected group of 22 severely disabled patients, the chronic posttraumatic syndrome was characterized by a wide variety of chronic symptoms, including headache and other PCS symptoms, which were aggravated by physical activity. All patients manifested delayed pain reaction to palpation of the mid-cervical facet joints, and nerve tension testing of the brachial plexus yielded pathological results in 50% of the cases. Radiographically there was a wide variety of moderate, segmental deviations at subaxial cervical levels in all patients; e.g., axillary pouch deformations, disc protrusions, or spondylotic stenosis. Certain patterns of segmental mobility abnormalities of the cervical spine were also manifest, though their detection required specific methods of assessing the functional flexion/extension radiographs.

As compared to a group of patients asymptomatic six months after a whiplash injury, and to a healthy control group, 20 patients with chronic posttraumatic syndrome were characterized by a higher frequency of oculomotor dysfunction.

In a casualty register study, the incidence of neck injuries was as high among women as among men, or higher. Women and men differed from each other in the manner in which their head and neck injuries were sustained and in type of accidents involved. PCS symptoms were more frequent after neck injuries than after minor head injuries. Both chronic symptoms and multiple symptoms were more frequently reported by women than by men.

In an autopsy study of traffic victims with head injuries, concomitant cervical injuries of the uncovertebral joints, facet joints, discs, and other soft tissues were
common, and such injuries were not detectable at routine autopsy or at radiographic examination.

In a single-case study, the findings were summarized in a hypothesis that the post-trauma symptoms are attributable to dysfunction of the brainstem, cervical segments, and brachial plexus, as suggested by the localization of changes subsequently seen at autopsy.

It is recommended that greater detail is required in traffic injury registrations, and that neck injury prevention be improved, taking into consideration women’s greater vulnerability to such injuries. A detailed physical examination and an analysis of segmental motion quality in functional flexion/extension radiographs, are suggested as diagnostic tools in the evaluation of chronic WAD and PCS patients. The results of these studies suggest the existence of a common pathogenic mechanism underlying the development of chronic PCS and WAD syndromes, and may provide the basis of improved diagnostics in cases of chronic disability after such injuries, as summarized in the single case study.

Key words: Whiplash injuries, posttraumatic syndrome, post-concussion syndrome, oculomotor dysfunction, segmental dysfunction of the cervical spine, occult cervical injuries, gender differences, brachial plexus dysfunction, flexion/extension X-rays, posttraumatic headache.
Sammanfattning (summary in Swedish)


Whiplashskador och tillstånd relaterade till sådana skador (WAD) utgör ett stort och ökande problem i form av personligt lidande, belastning på sjukvården och kostnader för samhället. Denna typ av skada och lätta skada (hjärnsskakning) har likheter med avseende på olycksmechanism och det förbryllande i att även lätta skador (AIS 1) kan ge svåra, kroniska invaliditetstillstånd. De patofysiologiska mekanismerna bakom utvecklingen av sådana kroniska tillstånd är dåligt känt. I avsikt att öka kunskapen om de biomedicinska aspekterna av WAD gjordes de studier som bildar underlag för denna avhandling. De viktigaste resultaten har summerats nedan.

I en selekterad grupp av patienter med svåra, kroniska besvär efter whiplash-relaterade skador utan inslag av skallskada förekom i hög frekvens en rik flora av symptom ingående i det cervikala syndromet, inklusive huvudvärk och andra post-commotionella (PCS) symptom (I-III), uttalade cervicobrachiella (TOS) symptom (I), tecken på störd hjärnstamsfunktion i form av asymmetriska förändringar vid oculomotor tests (III), tecken på dysfunktion i den segmentella rörligheten i halsryggen, både vid manuell undersökning och mätt med olika analysmetoder på röntgenbilder i flexion och extension (I och II), samt tecken på dysfunktion i nervflätan till armen (plexus brachialis (I)).

I en enkätstudie av 1.063 personer med lätt skall- eller nackskada, rapporterades 1 – 3 år efter olycksfallet kronisk huvudvärk och andra PCS-symptom oftare efter nackskador av whiplashtyp än efter lätta skallskador som hjärnsskakning (V), kroniska nackrelaterade besvär övändat ofta efter rena skallskador (V) samt högre prevalens av både PCS- och nackrelaterade kroniska besvär jämfört med oselekterade populationer (V).

Halsryggsskador förekom i hög frekvens i en grupp trafikdödade med skallskador, i synnerhet facettedledsskador, uncovertebrale skador och diskrupturer, både multipla och isolerade (VI). Huvudparten av dessa skador gick inte att upptäcka, vare sig vid rutinobduktion eller på högklassiga röntgenbilder (VI).

Resultaten tyder på att det kan finnas gemensamma, biomedicinska mekanismer bakom utvecklingen av kroniska posttraumatiska syndrom efter lätta skall- och nackskador. Gemensamt för alla dessa resultat är också att de inte bjuder sig självmant vid rutinundersökningar eller med de oftast använda forskningsmetoderna. Det är först vid en detaljerad anamnesupptagning, med en utvidgad fysikalisk un-
dersökning inkluderande ett nervsträcktest, med specifik testning av oculomotorfunktionen, med en detaljerad analys av rontgenbilderna och en utvidgad patologanatomisk analys av halsryggen som dessa resultat kommer till synes.

Detsamma kan sägas gälla för de skilda könsmönster som framkom i flertalet studier. Först efter detaljanalys av olycksfallsregistren och akutjournalerna kan man skönja skillnaderna: Jämfört med männen får kvinnorna oftare lätt skall- och nackskador som passagerare och fotgängare och i bak- och sidopåkörningar. Jämfört med kvinnorna får männen oftare sådana skador som motorfordonsförare i frontalkollisioner och singelolyckor (IV).

Även i icke trafikrelaterade olyckor kan liknande mönster skönjas: Flickor och kvinnor skadar sig i fallolyckor i ensamspor ts som ridning och gymnastik samt i hemmet eller under promenad. Pojkar och män krockar med andra män eller med föremål i lagsporter som ishockey och fotboll samt pa arbetet och i fritidsaktiviteter, i de sistnämnda påtagligt ofta med alkohol inblandat (IV).

Ett återkommande könsmönster i studierna är att kvinnorna dominerar gruppen patienter med kroniska besvär efter dessa skador (I – III och V), de rapporterar fler kroniska besvär (I och V) och i oculomotorstudien (III) var det endast kvinnor som företade tecken på allvarlig hjärnstam dysfunktion, alternativt hjärnstamsskada (fyra patienter).

I avhandlingen ingår en fallstudie (VII) av en patient som utreddes i enlighet med delarbetena I – III efter en skallskada med symptom på samtidig whiplashrelaterad nackskada, och som 12 år senare avled, varefter halsryggsskadorna analyserades patologanatomiskt i enlighet med delarbete VI. Resultaten i den studien kan sammanfattnas i en hypotes, representativ för hela avhandlingen: Den gemensamma biomedicinska nämnaren vid kroniska WAD-, TOS- och PCS-tillstånd kan vara en posttraumatisk dysfunktion i halsryggens segmentella rörlighet med sekundär dysfunktion i hjärnstammen och nervfläten till armen.
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