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Epidemiology and Surgery in Traumatic Cervical Spine Fractures

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Epidemiology and Surgery in Traumatic Cervical Spine Fractures

A doctoral thesis

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November, 2016

Hege Linnerud Fredø
2. LIST OF PAPERS

This thesis is based on the following papers:


3. ABBREVIATIONS (in alphabetical order)

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AOD</td>
<td>Atlanto-occipital dislocation</td>
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<tr>
<td>ACDF</td>
<td>Anterior cervical disectomy and fusion</td>
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<tr>
<td>AISA</td>
<td>American Spinal Injury Association impairment scale</td>
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<tr>
<td>ALL</td>
<td>Anterior longitudinal ligament</td>
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<td>CCS</td>
<td>Central cord syndrome</td>
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<tr>
<td>cSCI</td>
<td>Cervical spinal cord injury</td>
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<tr>
<td>C1-fx</td>
<td>Fracture of first cervical vertebrae</td>
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<tr>
<td>C2-fx</td>
<td>Fracture of second cervical vertebrae</td>
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<tr>
<td>CT</td>
<td>Computer tomography</td>
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<td>CCT</td>
<td>Cervical computer tomography</td>
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<td>CS-fx</td>
<td>Cervical spine fracture</td>
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<tr>
<td>CSI</td>
<td>Cervical spine injury</td>
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<td>CSISS</td>
<td>Cervical Spine Injury Severity Score</td>
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<tr>
<td>DLC</td>
<td>Disco-ligamentous complex</td>
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<tr>
<td>GCS</td>
<td>Glasgow Coma Scale</td>
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<tr>
<td>HISS</td>
<td>Head injury severity scale</td>
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<tr>
<td>ICD</td>
<td>International Statistical Classification of Diseases and Related Health Problems</td>
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<tr>
<td>ICU</td>
<td>Intensive care unit</td>
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<tr>
<td>MRI</td>
<td>Magnetic resonance imaging</td>
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<tr>
<td>NPR</td>
<td>Norwegian Patient Register</td>
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<tr>
<td>OC</td>
<td>Occipital condyle</td>
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<td>OC-fx</td>
<td>Occipital condyle fracture</td>
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<tr>
<td>Abbreviation</td>
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<td>------------------------------------------------</td>
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<td>OR</td>
<td>Operating room</td>
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<tr>
<td>OUS-U</td>
<td>Oslo University Hospital - Ullevål</td>
</tr>
<tr>
<td>PLL</td>
<td>Posterior longitudinal ligament</td>
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<tr>
<td>ROM</td>
<td>Range of motion</td>
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<tr>
<td>SCI</td>
<td>Spinal cord injury</td>
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<tr>
<td>SCIM III</td>
<td>Spinal Cord Independent Measure</td>
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<tr>
<td>S-CS-fx</td>
<td>Subaxial cervical spine fracture</td>
</tr>
<tr>
<td>SBP</td>
<td>Systolic blood pressure</td>
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<tr>
<td>STSG</td>
<td>Spine Trauma Study Group</td>
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4. INTRODUCTION

4.1 Cervical spine anatomy and biomechanics

The bony parts of the cervical spine consist of seven vertebral bodies (C1-C7) that are linked by intervertebral discs, ligaments, and muscles, which provide stability and mobility to the spine (Figure 1).

The cranio-cervical junction is included as part of the cervical spine. The occipital condyles (OC) are considered the highest anatomical structure of the neck. In terms of trauma, fractures of the OC are considered a cervical spine injury, even though the strict anatomical classification is a skull base fracture. Caudally, the disco-ligamentous complex (DLC) between the seventh cervical (C7) and the first thoracic (Th1) vertebrae is also regarded as part of the cervical spine. The range of motion (ROM) of the cervical spine in a young person...

Figure 1. CT scan showing a sagittal (A) and coronal (B) view of the normal cervical spine.
is ~ 80°-90° of flexion, ~70° of extension, ~20°-45° of lateral flexion, and ~90° of rotation to both sides.\textsuperscript{6}

\textbf{OC-C2 segment:} The upper cervical spine consist of OC-C2 and its accompanying ligaments (Figure 2). There are no intervertebral discs in the upper segment, and C1 and C2 are more specialized than the other cervical vertebra. C1 (atlas) is ring-shaped and lacks a vertebral body, while C2 (axis) contains the characteristic odontoid process. The stability of the OC-C1 joints (also called the YES-joints) is maintained by continuous spinal ligaments that both attach from C1 to the skull base as well as ligaments running from C2 to the basal cranium (the alar ligaments and the apical odontoid ligament). The inner anterior C1 ring also forms a joint with the C2 odontoid process, which is stabilized by the transverse ligament. This joint allows a pivoting motion of the upper cervical spine as C1 rotates around the odontoid of C2. The odontoid process has a relatively reduced osseous vascularity, resulting to a vulnerability with respect to bone healing in cases of fractures. The facet joint capsules of the upper cervical spine have a relatively high laxity compared with the capsules in the lower cervical levels, facilitating mobility. Collectively, the upper cervical spine is responsible for 50% of the total neck flexion-extension at the atlanto-occipital (OC-C1) joint as well as 50% of the total neck rotation at the atlanto-axial joint (C1-C2).\textsuperscript{7}
Subaxial segment: The subaxial cervical spine consists of the C3-C7 vertebrae and is a more uniform entity. The vertebrae are anatomically roughly identical, except that the size increases steadily downward, and there are some minor differences in terms of the shape and angulation of the joint surface facet. Between each vertebral body is a fibro-cartilage intervertebral disc, representing the largest avascular structure in the human body. The discs help to sustain compression loads and to resist tension, tear and torsion during movement. The intervertebral disc constitutes the anterior “joint” between the subaxial vertebrae, while the two facet joints with mechanically resistant joint capsules constitute the posterior articulating bony surfaces between the levels. In addition, there are ligaments that are crucial for maintaining stability and allowing mobility that runs continuously along the spine from the sacrum all the way to the occiput (the anterior longitudinal ligament (ALL) and the posterior longitudinal ligament (PLL)). The interspinous ligaments attaches the spinous processes up to C2, and the

Figure 2. The ligaments of the upper cervical spine. Coronal view (A) and sagittal view (B).

ligamentum flavum runs segmentally from C1 to the sacrum. There are also ligaments that connect the lateral borders of the vertebrae called the intertransverse ligaments (Figure 3). The subaxial cervical spine accounts for the remaining 50% of neck flexion, extension and rotation, the largest amount of rotation in the higher subaxial levels due to the orientation of the facet joints.

![Figure 3. The ligaments of the subaxial spine.](https://stockmedicalart.com)

There is a fine and crucial balance between mobility and stability in the cervical spine. Stability is mandatory to protect the neural structures that are closely associated with the column; the spinal cord inside the central canal of the vertebrae, and the pairwise nerve roots leaving the central canal bilaterally at each level, running through a bony foramen made up of
the bony joints. The alignment between each level is essential for maintaining the appropriate space and course for these structures.

The vertebral arteries run bilaterally through the foramen of the transverse processes of the vertebrae, most frequent entering caudally in the foramen at C6, providing the posterior circulation of the brain (Figure 4).

![Figure 4. CT angiogram of the vertebral arteries (white arrows). Coronal view (A) of the vertebral arteries running through the transverse foramina of C2-C6. Axial view (B) of C5 with the vertebral arteries running through the transverse foramina.](image)

### 4.2 Definition of traumatic cervical spine injury

The direct mechanical force leading to a cervical spine injury (CSI) is more often to the head or the truncus than to the neck itself. The characteristics of the term traumatic CSI depends on
the definition used. This thesis does not address low-impact injuries such as micro-fractures and sprains to the DLC, which do not cause malalignment, instability or neurological injury. Micro-fractures are not visible on computer tomography (CT) but are diagnosed by magnetic resonance imaging (MRI). In the acute phase, they are observed as edema in the bone marrow of the vertebrae. If these findings are not accompanied by a loss of vertebral height, dislocations, and/or fracture lines upon skeletal radiographic examination, these fractures will currently be lost for diagnosis in the absence of an MRI assessment; historically, of course, they were never identified. In terms of treatment, this is not a concern because the only necessary treatment is symptomatic. In other words, implementation of the MRI has not changed the way these patients are treated, but it exemplifies the challenges associated with defining CSI.

Implementing MRI in the acute phase after CSI has also led to the diagnosis of DLC sprains without coinciding dislocations; historically, most of these injuries were never acknowledged. In MRI studies of the obtunded trauma patient with a normal CT scan of the cervical spine, pathological MRI findings are obtained in up to 20% of patients. However, the rate of CSI in need of surgery detected by supplementary MRI is, in most reports, ≤ 1%. The clinical impact of many of these MRI findings may be difficult to determine. In the majority of patients with a positive MRI, there will be signs of inflicted sprains to the DLC (edema) without any potential for dislocations, and with no need for any measures.

Head movement during the infliction of trauma was previously considered to offer significant information regarding the type of CSI. However, this notion is much too simplified because a “clean” vector effect on the spine rarely occurs. The observed motion of the head during injury is not a reliable indicator of the spine movement responsible for creating the injury. In my work, I have addressed traumatic cervical spine fractures (CS-fx) that are visible on CT as well as the continuous fractures in osteopenic, ankylosic and degenerative spines that are
only visible on MRI. The latter are not to be confused with microfractures but are clinically highly relevant fractures that may be hard to identify on CT scans (and plain x-rays) due to osteoporosis of the skeleton. I have also addressed the injuries of the DLC without coinciding CS-fx, in which ligament rupture has resulted in dislocations of the spine. In summary, my aim was to investigate all severe and potentially unstable CSI.

4.3 Epidemiology

Historically, the typical CS-fx patient has been a male aged 15-40 years suffering from a high-energy trauma with a high risk of spinal cord injury (SCI).11-28 Nearly all published papers on CS-fx epidemiology are from subgroups of trauma-center patients, specific age groups, head injury patients, patients with other specific organ injuries, military populations, and patients with specific trauma mechanisms (pedestrians, diving, horseback riding, trampoline, soccer, among others).11,13,16-19,22,25,27-41

Gender: All publications report uniform findings regarding the gender distribution of CS-fx, with ~70% male - and ~30% female patients.11,13,15,17,18,22,23,26,28,42-44 The distribution in the subgroup of elderly patients with odontoid fractures differs from that in the total CS-fx population, with 50-60% female patients.45-47

Age: Almost all publications report that the highest incidence and/or frequency of CS-fx is found in young adults, with some minor differences in the age groups referenced.13,15,18,21-24 Recently, some publications reported a bimodal age distribution, with the highest frequency observed in young adult life and a second “peak” in patients aged 65-80 years.12,24,26,28,29,43 All papers uniformly report a low incidence of CS-fx during childhood.12,25,29,36,43

Trauma mechanism: The two most frequent trauma mechanisms leading to CS-fx are uniformly reported as motorized vehicle accidents and falls.12,15,19,21,22,25,26,28,44 Other fairly frequent mechanisms are bicycling, pedestrian accidents, sports and diving. The majority of
publications report motorized vehicle accidents as by far the most frequent mechanism responsible for CS-fx. Recent publications report a higher proportion of falls as the trauma mechanism responsible for CS-fx.12,21,26,28,42,44

SCI: In CS-fx patients, the percentage of SCI is reported as 12-50%.12-19,21 In the majority of publications, the rate of coinciding SCI with CS-fx is reported to be as high as 30-50%. Studies of trauma-center patients have provided the basis for our current knowledge regarding the demographics of CSI, and the incidence of CS-fx has mainly been presented as a percentage of the trauma center patients, ranging from 2 to 7%.13,17,22,23,28,35,43,44

Incidence: We found three previous publications that reported an incidence of spine fractures in the general populations, of which only one focused on cervical spine trauma. A Swedish study from 2002 published CS-fx numbers from a nationwide population.20 Based on patient data from 1987 to 1999, the incidence of Cs-fx in the Swedish population declined from 10.5/100,000/year in 1987 to 9.2/100,000/year in 1999. The proportion of CS-fx patients with a concomitant spinal cord injury (cSCI) in this Swedish study was 51% (1987) and 36% (1999). A Canadian study conducted in 1996 reported an incidence of spine fractures at all sites of 64/100,000/year.14 Subgrouping into cervical, thoracic or lumbar fractures was performed for only 45% of the patients who were admitted to the hospital. In these patients, the involved site was cervical in 19% of patients, thoracic in 30% of patients, lumbosacral in 43% of patients, and unspecified in 8% of patients. If we assume fractures at all levels were admitted to the same extent, these values would provide an incidence of CS-fx in this population of 12/100,000/year. A condition for this assumption is that 55% of the patients with acutely diagnosed CS-fx were not hospitalized, which seems unlikely. It would be expected that a larger proportion of the patients with uncomplicated thoracolumbar fractures were treated as out-patients, and if so, the incidence of CS-fx in this population was lower than our estimate. The third study is from Western Ireland, where they have investigated spine
trauma in need of hospitalization within a regional trauma unit over a four-year period. They have estimated the annual incidence of traumatic spinal injury at all sites to 19.5/100,000/year, among which 18% of the cases had a cervical level injury. From this study, an incidence of hospitalized cervical spinal trauma of 3.6/100,000/year can be estimated.

To summarize, the publications examining the epidemiology of CS-fx to date are mainly from subpopulations, and the few studies of general populations show significant variations in their reported results.

4.4 Imaging

The history and clinical examination of the trauma patient determine the need for a radiographic evaluation of the cervical spine, independent of the trauma mechanism.

Trauma cases fulfilling all the following criteria are not in need of cervical imaging:

- Awake and communicating
- No neck pain
- Normal neurological status
- No distracting injury
- Normal cervical ROM

Cervical imaging is strongly recommended in trauma patients if the following are observed:

- Symptomatic (neck pain and/or neurological deficits)
- Distracted by other injury
- Obtunded/unevaluable

Cervical computer tomography (CCT) with 2-D reconstructions in three planes is the first choice type of radiographic imaging in trauma patients. CCT has a sensitivity permitting the detection of CSI after blunt trauma of 98%.
Plain cervical spine x-rays have a sensitivity as low as 37-64% for detecting CSI.\textsuperscript{50-53} Plain x-rays are only to be used as an initial examination if CCT is not available and transportation of the patient is not possible.

In the awake symptomatic patient with a normal CCT, the characteristics of the symptoms, patient age and mechanism of trauma are decisive factors concerning whether to

- continue cervical immobilization until asymptomatic
- discontinue cervical immobilization at the discretion of the treating physician
- supply further imaging (MRI and/or flexion-extension x-rays)

In the obtunded or unevaluable patient with a normal CCT, we can choose among three strategies:\textsuperscript{8}

1. Continue the cervical immobilization until the patient is accessible for clinical testing. This might be relatively contraindicated in multi trauma/severe head injury patients because cervical orthoses have been associated with a modest increase in intracranial pressure and local pressure sores/skin breakdown\textsuperscript{54-56}

2. Discontinue cervical immobilization after a normal MRI study obtained within 48 hours of injury

3. Discontinue cervical immobilization at the discretion of the treating physician based on clinical judgement

MRI. A meta-analysis concluded that MRI reveals traumatic abnormalities in 12% of trauma patients with a normal CCT, among which half are considered in need of treatment (1% required surgery, 5% external immobilization).\textsuperscript{57} There is a broad consensus that MRI is the most sensitive imaging modality for the detection of SCI and DLC injury.

It is not always feasible to perform MRI within 48 hours in patients who are severely injured. The general clinical condition might be so unstable that transportation for an MRI and the limited monitoring facilities inside the MRI lab are regarded as unnecessary risks.
MRI of the traumatized spine should include a fat-suppression T2 series because edema is of major interest. An early MRI can help distinguish between degenerative and trauma-induced dislocations. In cases of poor bone quality and/or ankylosing spondylitis, the MRI can reveal fractures of major clinical interest that are not visible on CCT. MRI can also permit the visualization of bone marrow edema that is not visible on CCT, which we refer to as microfractures. These are not of major clinical interest in isolation, but they may be decisive factors in the choice of a surgical approach.

MRI is the only imaging modality that offers direct visualization of the spinal cord and nerve roots and provides the best radiological opportunity to consider injury and/or compression to the nerve structures. Finally, MRI is the most sensitive modality with regard to the diagnosis of DLC injury, especially in situations without major dislocations. However, these MRI findings are often very difficult to interpret in terms of clinical and treatment-related relevance. In a minority of cases, we can observe certain rupture of the ligaments, but the most frequent finding is edema in the discs, ligaments, and muscles.

*Dynamic flexion/extension studies* are usually performed under fluoroscopic guidance but may also be performed using a CCT or MRI scan, with the aim of identifying pathological movement/instability. The dynamic MRI may additionally reveal decreased space for neural elements during movement. Previously, dynamic x-rays were a commonly used diagnostic test for clearance of the cervical spine. With the more widely used CCT and MRI, dynamic studies have become less common. In selected patients with MRI findings for DLC injury with unclear significance, dynamic imaging might facilitate clarification. It must be kept in mind that a rather large share of the dynamic fluoroscopic examinations are inadequate because of problems with visualizing the whole cervical spine and/or inadequate motion.

*CT and MRI angiography* of the neck (pre-cerebral arteries) are supplementary examinations to be considered in cases of:
• major cervical spine dislocations
• when fracture lines affect the transverse foramen
• penetrating trauma of the neck
• expanding cervical hematoma
• neurologic deficits inconsistent with cranial CT findings
• cerebral ischemia after trauma
• fracture of the first rib

4.5 Clearance of the cervical spine

The majority of trauma patients are brought to the hospital with external immobilization of the cervical spine, most frequently a collar.

• In awake, alert patients without neck pain and neurological symptoms, without distracting injuries, and with a normal ROM, external immobilization can be discontinued without any imaging examinations.8
• In awake, alert patients with neck pain as the only symptom, a CCT is recommended. If the CCT shows no traumatic changes, the patient age, the character of the pain, and the medical history of the patient provides the foundation for the judgement of the clinician whether to discontinue the external immobilization or to perform supplementary imaging.8
• In awake patients with new neurological deficits, a CCT is the first choice radiographic assessment. If the CCT does not reveal any traumatic changes, an MRI is recommended. If the MRI does not reveal any pathology, it will be the up to the judgement of the clinician, considering the total clinical history, examination, and the assessment, whether to continue the collar treatment.8
In the obtunded, unevaluable trauma patient, a CCT is recommended. If the CCT is normal, the options are to supply an early cervical MRI, continue or discontinue the external immobilization, based on the discretion of the clinician.8

4.6 Cervical spine injuries: classification and treatment

4.6.1 Occipital condyle fractures

Figure 5. CT scan demonstrating a right-sided occipital condyle fracture in 3 planes (white arrows). A. axial, B. coronal, C. sagittal.

Occipital condyle fractures (OC-fx) have historically been considered an uncommon injury, most likely due to the low sensitivity of plain x-rays. In a meta-analysis, the calculated sensitivity for revealing OC-fx on plain x-rays was 1.4%.58 The sensitivity for CCT to depict OC-fx has been calculated to be 100% (Figure 5).58 The increasing use of CT scans for head and cervical injury has resulted in more frequent recognition of these injuries. In a study conducted in 2009, the yearly incidence of OC-fx in a trauma population was 1.7/1000 trauma patients.59 In our own epidemiology study in Southeast Norway, we estimated an incidence of OC-fx in the general population of 0.6/100,000/year.60
OC-fx has been classified by Anderson and Montesano into the following 3 types: Type 1 (comminuted), Type 2 (extension of the linear basilar skull fracture) and Type 3 (avulsion of a fragment). In 1997, Tuli and coworkers proposed a modification of the classification and guidelines. They divided the OC-fx into Type 1 (non-displaced, stable), Type 2A (displaced but intact atlanto-occipital junction, stable), and 2B (displaced, atlanto-occipital joint space widening, unstable).

Tuli proposed that the non-displaced OC-fx is not in need of external immobilization. The displaced OC-fx without signs of dislocation in the cranio-cervical junction (Type 2A) was suggested to be treated with a stiff collar. The displaced OC-fx with concomitant signs of cranio-cervical dislocation (Type 2B) should be treated with a Halo-vest or open surgery. The bony fracture patterns in isolation have been less emphasized in recent years in terms of treatment guidance because it is recognized that non-surgical treatment with external immobilization for 6-12 weeks is sufficient in nearly all types of isolated OC-fx, even bilateral ones. In line with Tuli’s proposals, it is only in cases of cranio-cervical instability due to secondary ligamentous disruption (recognized by displacement of the cranio-cervical junction on CCT, or certain ligament rupture on MRI), open surgery with cranio-cervical fixation or a Halo-vest may be indicated. Open surgery may also be indicated for neural compression from displaced fracture fragments. Lower cranial nerve deficits (the Collet-Sicard Syndrome) are a rare, but well recognized, complication of OC-fx. SCI associated with OC-fx is rare and will be discussed under cranio-cervical ligamentous injuries.

### 4.6.2 C1 fractures

Isolated fractures of the C1 (C1-fx) can occur in the anterior or posterior arch, lateral mass, or combined anterior/posterior arch fractures (Figure 6). The integrity of the transverse ligament is the crucial factor when determining the instability potential and treatment modality. For an
isolated fracture of the atlas with an intact transverse ligament, cervical immobilization with a collar is recommended.\textsuperscript{63,65} This applies to the gross majority of these fractures. In the small proportion in which the transverse ligament is ruptured, surgical fixation or external immobilization with a Halo-vest is recommended.\textsuperscript{65} Evaluation of the transverse ligament integrity is conducted as follows:

- By applying “Spence’s rule”, which is a measure of the bony “blasting”/overhang of the lateral masses of C1 in relation to the lateral masses of C2.\textsuperscript{66} This is best assessed by coronal plane views, preferably by CT, where a total lateral displacement in the sum of the two sides $\geq 7$ mm is considered a certain sign of transverse ligament rupture (Figure 7).

- Measuring the pre-dental interval, which is the distance from the anterior C1 ring to the odontoid in the sagittal plane (Figure 8).\textsuperscript{67} In general, this space is less than 3 mm in adults and less than 5 mm in children. When this interval is more than 5 mm in adults, it is considered a certain sign of transverse ligament rupture.

- By detection of ligament rupture on MRI.\textsuperscript{68,69}

In isolated C1-fx with transverse ligament rupture, posterior screw fixation C1-C2 or subocciput-C2 is the surgery of choice.\textsuperscript{70}

C1-fx are frequently associated with C2 fractures (C2-fx) and/or upper cervical ligamentous injuries. In these cases treatment is guided based on the concomitant injury.
Figure 6. CCT axial view of C1 showing fractures (white arrows) of the posterior arch (A), anterior arch (B), and the left side lateral mass (C).

Figure 7. Spence’s rule of lateral mass overhang in the coronal view. The overhang in mm on each side is summed, and a total of ≥7 mm is considered an indication of transverse ligament rupture. Illustration from Bono et al. Measurement Techniques for Upper Cervical Spine Injuries: Consensus Statement of the Spine Trauma Study Group. Spine 2007; 32: 593-600. In courtesy Wolters Kluwer Health, Inc.
4.6.3 C2 fractures

C2-fx can be divided into odontoid fractures, hangman fractures, and other fractures.

*Odontoid fractures* are the most frequent C2-fx and constitute up to 20% of all CS-fx.\(^{60,71-73}\)

Anderson and D’Alonzo have classified these fractures into three subclasses: Type I as a fracture in the tip of the odontoid peg, Type II in the base of the peg, and Type III running down into the body of the vertebrae (Figure 9).\(^{74}\) In 2005, Grauer et al proposed a treatment-orientated modification of the Anderson- D’Alonzo classification.\(^1\) They proposed a clarification to distinguish between Type II and III fractures, adding that it was not sufficient that an odontoid fracture runs downward into the body, but the fracture line should also extend laterally into the joint surface, to be classified as Type III (Figure 10). Additionally,
they further subdivided the Type II fractures regarding fracture patterns that are used to recommend a surgical approach (Figure 11).

**Figure 9.** Anderson and D’Alonzo’s classification of odontoid fractures. Coronal and sagittal drawing. Note that Type I injuries are at the tip of the odontoid. Type II injuries are at the base of the odontoid. Type III injuries extend into the cancellous C2 body.


**Figure 10.** Distinction between Type II and Type III odontoid fractures, clarified by Grauer et al. Coronal view of C2. The left drawing shows a Type II fracture according to Grauer but Type III according to the original definition by Anderson and D’Alonzo. The right drawing shows a Type III fracture according to Grauer (fracture lines extending laterally into the joint).

The therapeutic strategies for odontoid fractures are either external immobilization with a collar or Halo-vest, or open surgery. No treatment is not a good option for patients with odontoid fractures.\textsuperscript{75} The main determinants for the choice of treatment are the fracture type, grade of displacement, and patient age. There is no Class I evidence guiding the management of patients with odontoid fracture, and especially for the elderly with Type II fractures, the published results are diverging.\textsuperscript{76,77} The treatment of the infrequent Type I odontoid fracture with collar immobilization has been reported to be successful in nearly 100\% of cases.\textsuperscript{74-76,78}

\textbf{Figure 11.} Grauer’s subdivision of odontoid fx Type II; subclass A, B and C. Illustration from Grauer et al. Proposal of a modified, treatment-oriented classification of odontoid fractures. Spine J 2005; %: 123-9.\textsuperscript{1} In courtesy Elsevier.
Surgical stabilization and fusion of significantly displaced Type II and III fractures is recommended.\textsuperscript{76,79-84} Significant displacement is defined as $\geq 5-6$ mm ventral displacement or $\geq 2$ mm posteriorly (Figure 12). Non-significantly displaced Type III fractures have a high rate of bony fusion with external immobilization alone, so this is the recommended first-line treatment for these fractures.\textsuperscript{76,83,85} The non-significant displaced Type II fractures in younger patients have a high rate of bony fusion with external immobilization alone, so this is the recommended first-line treatment in these patients.\textsuperscript{74,76,83,84,86-88} The cut-off age between younger and older patients have typically ranged from 50 to 60 years.\textsuperscript{74,76,83,84,86-88} The recommendations propose a cut-off of 50 years old.\textsuperscript{76} The major controversy in odontoid fracture treatment is how to treat elderly patients with a non-significantly displaced Type II fracture.

\textbf{Figure 12.} How to place the lines when measuring anterior (or posterior) displacement of odontoid fractures. Drawing of C2 in the sagittal view.

The treatment options for odontoid fractures are, as mentioned previously, external immobilization or open surgery. External immobilization can be achieved by a semi-rigid collar or by a more rigid cranio-thoracic vest (the Halo-vest is most frequently used). The Halo-vest treatment is associated with a high morbidity and mortality rate in the elderly, and its use in this patient group is therefore controversial.80,87,89,90

Surgical options for odontoid fractures are as follows:

1. Anterior odontoid screw fixation, as described by Bohler in 1982 (Figure 13).91 This is the only surgical technique that preserves motion in the atlanto-axial segment. Contraindications to this technique are rupture of the transverse ligament or other significant ligamentous injury, substantial osteoporosis, fracture comminution of the C2 body or odontoid, Grauer Type IIC, a major displacement that cannot be reduced, and old/chronic fracture. If the fracture is more than 6 months old, the fusion rate with this surgical technique is inferior to other techniques.72,92 One study also demonstrated a significantly lower fusion rate with no more than a one week delay from injury to surgery, compared to those undergoing surgery within one week.93 Some surgeons perform this fixation using one screw, whereas others use two. A retrospective patient review found no significant differences in union rates between the groups with one versus two screws.94 Another center published their experience, also as a retrospective review, and concluded that the stability at the long-term follow-up was significantly greater in the group fixated with two screws versus one.95

2. Posterior wiring of C1-C2 lamina with a bone graft from the iliac crest has historically been the most frequently used technique, and it is still regularly used in many places despite being abandoned in others in favor of screw fixations (Figure 14). This technique was first described by Gallie in 1937 and requires intact posterior bony conditions on the C1 and C2 lamina.96 The fusion rates are in general high but inferior
to the posterior screw fixations.\textsuperscript{72} Posterior C1-C2 wiring will significantly restrict C1-C2 motion.

3. Posterior lateral mass screw fixation of C1 with a rod-associated C2 screw in the lamina, pars or pedicle is a frequently used technique, with a high fusion rate and lower complication rate than the comparable posterior screw fixation ad modum Magerl.\textsuperscript{97} This technique was first described by Goel and Laheri, and later modified by Harms and others (Figure 15).\textsuperscript{98-102}

4. Magerl and Seeman presented the posterior transarticular screw fixation of the atlas and axis in 1987.\textsuperscript{102} This procedure is in use by many, although it has been shown to have a higher complication rate than the alternative posterior screw fixation technique.\textsuperscript{97}

5. Anterior transarticular screw fixation of C1-C2 was described by Sen et al in 2005.\textsuperscript{103} Thus far, this technique is not widely used.

6. A reactivated technique that was first abandoned some years ago is the bilateral C1-C2 claw or hooks. With improved and allegedly more suited equipment available, this procedure was reported as a good option for posterior fixation C1-C2 in 2009.\textsuperscript{104,105}

7. In cases with odontoid fractures and other coinciding high cervical fractures and/or ligamentous injuries in the OC-C2 complex, cranio-cervical screw fixation is an option (Figure 16).
**Figure 13.** Sagittal CCT of an odontoid fracture Type II Grauer subclass B with posterior displacement (left image). Status after reposition and fixation with anterior odontoid single-screw fixation (right image).

**Figure 14.** Plain x-ray lateral view of the upper cervical spine showing bilateral wiring C1-C2 (black arrow) and an inter-laminar bone graft (white arrow).
Figure 15. Sagittal CCT of a posterior dislocated odontoid fracture (left image). Postoperative image (right) after fixation with posterior C1-C2 rod-associated screws. C1 screws in the lateral mass; C2 screws in the pars/pedicle.

Figure 16. Plain x-ray lateral view after cranio-cervical fixation from the subocciput to C2 (pedicle screws) and C3 (lateral mass screws).
Hangman fractures (traumatic spondylolisthesis of the axis) are much less frequent than odontoid fractures. These are bilateral fractures through the pedicles/pars interarticularis of C2, which divides the anterior and the posterior bony columns of the axis (Figure 17 A, B). The classifications of these fractures proposed by Effendi et al (with a modification by Levine and Edwards) and Francis et al have been most widely used. The fractures are classified according to the degree of displacement/translation/angulation of C2 on C3 over the disc-space, and the C2-C3 facet dislocations. The majority of Hangman fractures heal within 12 weeks of cervical immobilization with either a collar or Halo vest, but surgery is considered in fractures with ≥3.5 mm translation, >11° angulation over the disc-space, and/or signs of significant facet joint subluxation. There are also reports of a 100% bony fusion rate with external immobilization alone, even on the more displaced/unstable Hangman fractures. Others argue that it makes no sense treating a translation in C2-C3 with external immobilization, as all agree that the same degree of displacement in C3-C4 should be treated surgically.

Surgical options include the following:

1. Anterior discectomy and fusion C2-C3, which by many is considered the best surgical option (Figure 17 C, D).

2. Dorsal C1-C3 fusion procedures allows direct access to the C2-C3 facets for reduction, but the additional muscle dissection required might be a disadvantage (Figure 17 E, F).

3. Direct pars fixation has been described as an alternative but requires limited disc and ligament injury, which by most would be considered an argument for non-surgical treatment.

Combinations of these approaches have also been used.
Figure 17. Hangman fracture with 9 mm ventral displacement, sagittal (A) and axial (B) view on CCT. First operated with anterior discectomy, partial reduction, bone graft, and plating with screws C2-C3. Postoperative CCT sagittal view (C). At 6 weeks, the control CCT revealed that the fracture complex and bone-graft was displaced (D). He had no local symptoms (swallowing, hoarseness, pain), nor neurological deficits. We decided to leave the anterior fixation material in place and add a posterior rod associated screw fixation. We positioned lateral mass screws in C1, C3 and C4, as shown in the postoperative lateral plain x-ray (E) and CCT sagittal view (F). After this procedure, the patient did well, and late follow-up CCT has shown bony fusion in both fracture lines, and of the anterior displaced bone-graft toward the ventral bodies of C2 and C3.
Other C2 fractures include miscellaneous fractures of the body, lateral masses, lamina, and the spinous process. The body fractures are treated with external immobilization, and the posterior lamina/spinous fractures are treated either with external immobilization or no specific treatment. The non-surgical handling of these other C2 fractures is successful in $\geq 99\%$ of cases.\textsuperscript{76,79}

4.6.4 Subaxial fractures

Classification: Subaxial cervical spine fractures (S-CS-fx) are considered one entity, comprising the fractures from C3 down to the junction of C7/Th1. Many classifications have been proposed over the years. In 1963, Holdsworth presented a classification with five patterns of trauma based on a two-column concept, emphasizing the importance of the posterior ligamentous complex.\textsuperscript{116} This classification system has not been widely applied in practice and has never been validated. In 1982, Allen and co-workers introduced their classification of cervical spine fractures and dislocations with six different categories and stages of severity within each category.\textsuperscript{117} This classification was mechanistically detailed and complicated. Measurements of reliability have been undertaken with rather inferior results, and the system is not widely used.\textsuperscript{118} Harris and colleagues proposed another mechanistic classification system in 1986, which, similar to Allen’s system, was highly detailed with respect to the assumed injury mechanism.\textsuperscript{119} When subjected to validation, this system also demonstrated a low validity and reliability.\textsuperscript{118} Nevertheless, the descriptive components of this system regarding anatomic injury have been widely adopted and serve as a basis for subsequent classifications. White and Panjabi presented a stability checklist for CSI in 1987, and for the first time injury to the nerve tissue was included.\textsuperscript{120,121} Many of their principles for
determining stability remain widely used, though not in a formal systematic manner. The checklist has never been validated.

In 2007, a working group of the Spine Trauma Study Group (STSG) surgeons under the leadership of Anderson introduced the Cervical Spine Injury Severity Score (CSISS). They divided each cervical spine segment into four columns, and depending on fracture lines and degree of skeletal displacement, each column was given a score. The total sum of the four columns led to a treatment recommendation. The validity and reliability of this system was tested and found very acceptable. However, the system is complicated, which is probably the main reason it has not been widely implemented, and it has been proposed that it is more suitable for research than clinical practice.

In 2007, Vaccaro and the STSG proposed the Subaxial cervical spine Injury Classification system (SLIC). The objective was to quantify stability leading to a treatment recommendation, and a weighted score was given to three parameters: 1. morphology, 2. status of DLC, and 3. neurological status (Table 1). The SLIC score is rather easy and fast to use in daily clinical practice, it takes the neurological status into consideration, and it leads directly to a treatment recommendation. It became the first classification for subaxial CSI to be implemented in daily use. The reliability and validity was initially found fairly acceptable, but it did not match the CSISS. Recently, the SLIC has been criticized, and an additional study examining its reliability has revealed additional inferior results.

In 2015, two new classifications for subaxial CSI were proposed. The first classification by Vaccaro and co-workers modified the AO Spine classification for thoracolumbar fractures for cervical spine purposes. Song and co-workers have proposed a system complementing the previous Allen and SLIC systems. Whether these new classifications will be widely implemented in clinics remains unknown. In our department, we have used the SLIC
recommendations since 2009/2010. Although we acknowledge the limitations of the classification, we still find it useful.

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<td>Continuous cord compression</td>
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Table 1. Subaxial Injury Classification (SLIC) scale

Treatment of S-CS-fx. Treatment recommendations based on the SLIC score are as follows:

- A total SLIC score ≤3 points; non-surgical treatment
- SLIC 4 points; equivocal, it is up to the surgeon’s discretion to determine non-surgical or surgical treatment
- SLIC ≥5 points; surgical fixation
A small group of fractures are stable and can safely be treated solely as symptomatic. These are the isolated fractures of the transverse and spinous processes without any signs of additional DLC injury.\(^{126}\)

The largest group of S-CS-fx are potentially unstable but considered to maintain their alignment in the healing process with the use of external immobilization alone. For these patients, we use a semi-rigid brace, but many centers also use the more rigid cranio-thoracic vest (Halo-vest). There is no consensus in the literature regarding the treatment length with bracing, but personal communications with both national and international centers suggest variations in the range from 4 to 12 weeks. In our department, we have traditionally treated patients with bracing for 12 weeks. Currently we have an ongoing clinical study randomizing patients with S-CS-fx who are not in need of surgery to 6 or 12 weeks of external immobilization with a collar.

The group of injuries with convincing unstable signs, dislocations, and/or nerve structure compression are treated with open surgery. No consensus or scientific evidence provide definitive guidelines regarding the surgical approach.\(^{127,128}\) More than one surgical technique may accomplish the same goals. The basic surgical goals are adequate decompression of the neural elements, restoration of alignment, and sufficient mechanical spinal stability. The techniques used are as follows:

1. Anterior fixation with discectomy/corpectomy, grafting and plating. This approach is the least traumatic to the soft tissue, and the safest surgical position for the patient. However, the mechanical fixation stability is inferior to the posterior techniques, but in most cases, it is sufficient (Figure 18 A, B).\(^{129}\)

2. Posterior fixation with screws and rods. Additional laminectomy is performed when necessary to decompress the spinal cord. Screws are most frequently placed in the lateral masses, but when the fixation extends caudally to C7 and the upper
thoracic levels, screws are more often placed in the pedicles. The use of spinal navigation may be beneficial for placing pedicle screws in a safe manner, and in cases with well-sized pedicles also more cranial than C7. Less frequent is the crossing laminar placement of screws. This is rarely possible in other subaxial levels than C7. Posterior screw fixation usually involves a minimum of two levels above and two levels below the unstable pathology. The result is a mechanically stable construction but with significant limitations of cervical spine movement (Figure 18 C, D).

3. A combination of both anterior and posterior fixation (360° fixation), offering the most mechanically stable construct, and allowing direct access to both the anterior and posterior located pathology. However, this surgery is most demanding for the patient with respect to positioning, surgical trauma including blood loss, and the duration of surgery. This 360° fixation technique is mainly applied in the most unstable translation and/or rotation injuries, and in cases of fractures in patients with ankylosing spondylitis (Figure 18 E).

The timing of surgery will be discussed in the section covering SCI.
4.6.5 Injuries of the discoligamentous complex

Traditionally, recognized severe DLC injuries have been traumatic dislocations of the cervical spine. The only former method that could rule out severe DLC injury in patients with no initial dislocation was the dynamic x-ray. This has changed during the last decade as MRI has

Figure 18. A young male involved in a motor vehicle accident. Trauma CCT (image A, sagittal view) showing a translation/bilateral luxation injury at C6/7. Clinically, he had a complete SCI (ASIA A). The SLIC score was 4 (morphology) + 2 (DLC injury) + 2+1 (neurology) = 9. He was acutely treated with open reduction and anterior disectomy, cage and plating (image B, postoperative CCT sagittal view). Because of the highly unstable injury, the anterior fixation was one week later supplied with posterior screw fixation C5-Th1; lateral mass screws in C5, and pedicle screws in C6-Th1 (image C (axial at C6) and image D (sagittal) showing postoperative CCT). The timing of the second surgery was directed by his multiple organ trauma and stability assessment. The combined anterior-posterior (360°) fixation is displayed in a coronal scout view (image E). Postoperatively, he was treated with a stiff collar for 12 weeks.
been increasingly used in the initial assessment of patients with CS-fx, and in trauma patients with negative CCT and symptoms that are highly suspicious of CSI. MRI has improved our ability to reveal DLC injuries, but as mentioned earlier, a rather large proportion of the pathological MRI findings are challenging to interpret in terms of stability.

The use of MRI has resulted in an increasing awareness of DLC injuries, which is reflected in the revised international classification of diseases (ICD). In the previous ninth revision (ICD-9), DCL injuries were not assigned any detailed diagnostic codes. In the revised ICD-10 a supplementary paragraph is added; the S13 section. The S13 section contains diagnostic codes for cervical dislocations and ligament injuries. Together with CS-fx, some degree of DLC strain will always coincide, but it will not necessarily be of clinical importance. Severe DLC injuries without CS-fx, or with clinically minor CS-fx, are a frequent finding (Figure 19 A-F).

At subaxial levels (C3-C7), DLC injuries are included in the SLIC classification. In high cervical level injuries (OC-C2), the fractures are classified according to the bony morphology, integrity of the transverse ligament, and additional signs of disc injury in the Hangman fractures. In OC-C2 level complex/combined injuries, it is the suspicion of ligamentous injury and the degree of dislocation that will determine the severity and the treatment of the injury.

Atlanto-occipital dislocation (AOD) injury was perceived to be an uncommon injury in patients who survive transport to the hospital. Improvements in the emergency management of patients, rapid transport, and better recognition of the injury (reconstructed CCT instead of plain x-rays) have resulted in more survivors of AOD in recent decades (Figure 20). AOD is often associated with severe traumatic brain injury, cranial nerve deficit, and SCI. Cranio-cervical fixation and fusion is the only treatment option and is recommended for these patients.
Figure 19. An example of isolated subaxial DLC injury that was initially missed. A 78-year-old woman involved in a car accident. Trauma CCT performed the same day revealed significant degenerative changes, no fracture lines, no trauma-induced malalignment, and facet joints in the normal position (image A; mid-sagittal view, B; left lateral sagittal, C; right lateral sagittal).

After three weeks, a new CCT was performed (image D, E, F) because of sustained mechanical neck pain radiating to both arms. A significant kyphosis at level C5/6 had evolved due to bilateral perched facet joints secondary to DLC injury (Facet joints C5/6 marked with white arrows).
4.6.6 Spinal cord injury

When managing patients with CSI, there are numerous objectives to our treatment, but we should never lose sight of the primary goal of preventing or minimizing a SCI (Figure 21).

Clinical assessment following SCI. The use of standardized tools for neurological and functional classification of SCI is recommended. A variety of neurological assessment

**Figure 20.** Teenage female involved in a car accident. She had non-sufficient respiration, hypotension and Glasgow Coma Score (GCS) 3 when the medical team arrived after 10-15 minutes. She was intubated and resuscitated with clear fluids at the scene of trauma. During the short transport period to the hospital, her pupils dilated. After initial stabilization, a trauma CT was conducted. The CCT coronal plane revealed a severe atlanto-occipital dislocation. The distance from the OC to the superior facet of C1 was 28 mm (white arrow). The normal OC-C1 distance in the age-group ≤18 is <2 mm. Cerebral CT showed reduced differentiation between white and gray matter and general edema but no primary brain injury. Her pupils did not retract in response to hyperventilation and hypertonic sodium fluid. She went into cardiac arrest within one hour after arrival, and heart resuscitation was not initiated.
systems/scales have been proposed and used over the years.\textsuperscript{2,134-140} The 2000 American Spinal Injury Association (ASIA) Standards is found most consistent, reliable and valid and is the recommended neurological scoring system.\textsuperscript{2,134,138} In a longitudinal follow-up, one should also use functional outcome scales and pain assessment classification instruments. To assess the functional abilities and patient impairment, the Spinal Cord Independent Measure (SCIM III) is the recommended system,\textsuperscript{134,141} and for pain assessment the International Spinal Cord Injury Basic Pain Data Set has been shown to have the highest reliability and validity.\textsuperscript{134,142}

\textbf{Figure 21.} An elderly male suffering a fall down the basement stairs in his home, causing an incomplete, but severe, SCI; ASIA B, clinical level C5. He had preserved sufficient respirational ability. Trauma CCT revealed substantial degenerative changes, but isolated fractures of the spinous processes at levels C3 and C4 were the only trauma-related pathology. An early MRI within the first few hours was conducted.

Image A is a fat suppression MRI T2 sequence (STIR), revealing substantial edema in the connective tissue and musculature ventrally and posteriorly to the spine (black stars), and edema and swelling of the spinal cord at level C3 and C4 (white parenthesis). Image B is a gradient echo T2 MRI sequence, showing intramedullary hemorrhage (white arrow).
In complete SCI, all motor and sensory function are lost at some point below the level of the injured spinal cord, including the sacral levels, according to the short-form ASIA impairment scale ASIA A (Table 2).² The prognosis after traumatic SCI ASIA A is severe. Although 10-20% of these patients convert to incomplete SCI within the first 18 months after trauma, only 1-8% gain volitional motor function, 0-4% gain some ambulatory ability.¹⁴³,¹⁴⁴ The larger part of recovery is gained during the first 3 months, and complete recovery potential is observed within 12-18 months. An increased mortality is observed among patients with complete SCI in comparison to incomplete SCI.¹⁴³

In incomplete SCI, there are at least some degree of motor and/or sensory function below the injured level, and mandatory for sacral segments. Incomplete SCI is graded as ASIA B-D, depending on the severity. The prognosis for recovery is better for incomplete than for complete SCI, and it improves with a less severe initial ASIA score.¹⁴³ The majority of ASIA C and D patients will be ambulatory at 1 year after trauma.¹⁴⁴

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<td><strong>B</strong></td>
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*Table 2. Short-form American Spinal Injury Association’s (ASIA) SCI impairment scale.*²
A variation of incomplete cervical SCI is called Central Cord syndrome (CCS). CCS is often observed after falls in the elderly with a degenerative central canal stenosis. These patients frequently have no or clinically less important traumatic fractures and/or dislocations. The centermost region of the spinal cord is a vascular watershed zone that renders it more susceptible to injury from edema. The somatotropic organization with cervical fibers located more medially than the fibers serving the lower extremities results in a clinical presentation with disproportionately greater motor deficit in the upper compared with the lower extremities. The clinical presentation of the syndrome consists of a wide variety of “burning hands” to more severe motor, sensory and bladder control deficits. There is often an initial phase of improvement, and the lower extremities recover first. It has been shown that 90% of these patients will be able to walk within 5 days of trauma.145 The patients with CCS and severe neurological deficits should be subject to the same medical and intensive care treatment as all other patients with acute traumatic SCI.146

Pathophysiology of SCI. The extent of both the initial tissue disruption and subsequent secondary injury is likely directly related to the energy delivered to the spinal cord at the moment of impact. The spinal cord is rarely anatomically transected after blunt injuries, even in patients whose motor and sensory deficits are deemed complete. It remains unknown how much of the spinal cord must remain intact in humans to mediate meaningful distal neurologic function, although some residual motor function has been observed in an incompletely paralyzed patient with approximately 7% of the normal number of axons below the injury level.147,148 However, varying degrees of spared neural tissue have been observed in postmortem studies of patients with clinically complete injuries.148,149 The majority of our understanding of the pathophysiologic processes initiated in the human spinal cord after blunt injury is derived from animal models. The primary injury is direct mechanical damage of axons. Additionally, a large number of axons are subsequently lost due to a variety of
pathophysiologic events (secondary injury) that are initiated by the original mechanical insult. The secondary events contributing to axon damage after spinal cord injury include alterations in microvascular perfusion, free radical generation and lipid peroxidation, necrotic and apoptotic cell death, and dysregulation of ionic homeostasis.\textsuperscript{150,151} These processes start immediately after the primary injury and accelerate over time. Toxic levels of free radicals have been demonstrated as soon as 15 minutes after the inflicted trauma, and medical attempts to treat the exitotoxicity in animals were effective when administered 5 minutes after trauma, but they were ineffective after four hours.\textsuperscript{151} However, apoptotic cell death can occur for weeks after the injury.\textsuperscript{151}

\textit{Pharmacological treatment}. Experimental knowledge of the aforementioned secondary pathophysiological processes after SCI has been fundamental for attempts to develop medical therapy. The neuro-protective strategies have been designed to target these responses. Promising results have been obtained in animal studies with numerous pharmaceutical agents, but human studies have either failed to detect or to reproduce a clinical effect.\textsuperscript{151,152} The most studied agents have been methylprednisolone, which has also been an established part of the treatment for acute SCI for some years, followed by ganglioside.\textsuperscript{151-158} However, opioid antagonists, glutamate receptor and ion channel antagonists/blockers, and cyclooxygenase inhibitors have been proposed as promising candidates, although not proven efficient in human studies.\textsuperscript{151} It is likely that the time from trauma to the earliest possibility to provide drugs is a significant impediment in terms of the clinical effect. However, knowledge of pathophysiological cascades that progress for weeks after trauma is important for ongoing trials.

\textit{Autonomic dysregulation} after SCI can be divided into acute and chronic processes, with some overlap. Acutely, neurogenic shock may occur with components of hypotension, hypothermia, and bradycardia and/or arrhythmias. Orthostatic hypotension occurs acutely, but
it is clinically often even more relevant when mobilizing the patient, and some patients are troubled by this over the long-term. Chronic manifestations of autonomic dysfunction include impaired temperature regulation and impaired cardiovascular function and responses to exercise.\textsuperscript{159} Autonomic dysreflexia is a potential life-threatening event for patients after SCI, especially after SCI at the level of Th6 or above. The clinical findings are characterized by an acute elevation of arterial blood pressure and bradycardia or tachycardia. The clinical expression can span a broad range from asymptomatic, to mild discomfort and headache, to life threatening emergencies.\textsuperscript{160}

\textit{Cardiopulmonary management} of patients suffering a SCI requires monitoring in an intensive care unit (ICU) or similar setting.\textsuperscript{161} Patients with acute cervical SCI frequently develop hypotension (systolic blood pressure (SBP) < 90 mmHg), hypoxemia (O2 saturation < 90%), pulmonary dysfunction, and cardiovascular instability. These physiological changes may be caused by the aforementioned autonomic dysregulation as well as by motoric deficits, hypovolemia, major surgery, infections, and concurrent trauma. The use of cardiac, hemodynamic and respiratory function monitoring devices is recommended to detect dysfunction for early treatment. Hypotension should be avoided, and correction of SBP < 90 mmHg as early as possible is recommended.\textsuperscript{161} The target mean arterial pressure should be 85-90 mmHg for the first seven days after SCI to improve spinal cord perfusion and ultimately the neurological outcome.\textsuperscript{161,162} A literature review on respiratory complications associated with acute SCI concluded that mortality, the incidence of respiratory complications, and the requirement for tracheostomy were all significantly reduced when a respiratory protocol was applied for SCI patients.\textsuperscript{163} They also demonstrated a reduced duration of mechanical ventilation and ICU stay.

\textit{Surgical decompression – timing}. Surgical decompression restores the space conditions for the spinal cord, either by reduction/realignment of the spine axis, or by removing space-filling
lesions (bone, ligaments, disc herniation, hematoma). Many studies have addressed the timing of surgery in the setting of SCI and medullary compression. In recent years, the most commonly used distinction between early and late surgery has been within or later than 24 hours after the trauma. An increasing number of publications have demonstrated the potential benefit and safety of early decompression with respect to neurological recovery. However, other publications have failed to show an effect of the timing of surgical intervention on outcomes after SCI. Additionally, patients with CSI may benefit from early surgery in terms of earlier mobilization, reduced hospital stay, and a decreased complication rate. A proportion of CSI patients will not be eligible for early surgery because of logistical/transport challenges, other life-threatening injuries demanding treatment priority, or a delayed diagnosis. In patients with SCI and medullary compression, there is increasing support in favor of performing the surgery as early as safely possible.

It is recommended that patients with CCS and a short-segment cord compression and/or fractures and dislocations are treated surgically with decompression/reduction and fusion, within the same principals as other SCI patients. The role of surgery for patients with acute traumatic CCS with long-segment cord compression/injury, or with spinal stenosis without bony injury, remains a subject of debate in the literature, both regarding surgical indication and the timing of eventual surgery. The age and co-morbidities of these patients are important factors for surgical decisions.

4.7 Surgical complications and outcomes

Complications. There is no international uniformly accepted definition or ranking system for surgical complications. Any evaluation of surgical performance will remain elusive, unless
there is a common methodology for reporting negative outcomes. The terms minor, moderate, major or severe complications are widely used, but the terms are inconsistently used among authors, centers, and over different time periods. Negative outcomes have been differentiated according to three types; complication, failure to cure, and sequela. It has been suggested that complications should be ranked by severity based on the therapy needed to treat the complications, ranging from any deviation from the normal postoperative course without the need for extraordinary treatment, complications demanding medical therapy, complications demanding surgery, complications demanding ICU treatment, and complications leading to organ failure, until the death of the patient. This classification has been evaluated after five years of international use, and it is considered to be valid and applicable. The criteria for a surgery-related complication is also a matter of interest and debate. Patient might have chronic medical conditions that influence the results, or they might develop a medical problem that is not obviously related to the surgery. It is common to preoperatively stratify patients into risk categories according to their physiological characteristics. There are numerous classifications in use, among which one of the most common is the American Society of Anesthesiologists (ASA) classification. Surgical mortality is most frequently defined as all patient death within 30 days after surgery, independent of the cause of death.

Whether complications are registered prospectively or retrospectively will clearly have a large impact on the accuracy and completeness of the records.

The usefulness of objective, comparable complication registrations will be as follows:

- Prevention. For surgeons and centers, knowledge of the types and rates of complications should be a constant source for preventable measures.
- Patient information.
• Grading of centers. This may work as a health-political tool in terms of organizing health-care, and as a quality assessment.

Possible negative side effects of complication registries can be risk adjustment, both regarding surgeons/centers that decline to participate in the highest risk cases as well as conservatism in medical practice rather than developing new techniques.

*The surgical outcomes* will depend on the condition treated. However, although there are specific outcomes measures of interest defined by each condition/surgical procedure, we can define general outcomes that are valid to all surgical procedures as follows:

• The degree of cure
• Sequela from treatment-related complications

Long-term outcomes after surgery will be more valid if compared to non-surgical treatment of the same condition, but this is not always justifiable or within ethical boundaries.

In terms of surgically treated CS-fx, the degree of cure will be related to the following:

• Bony fusion
• Alignment
• Neurological status compared to pre-treatment
• Pain

Sequela from treatment related complications might consist of the following:

• Common complaints related to the surgical approach/technique (swallowing difficulties, hoarseness, pain, restricted cervical spine movement)
• Worsened neurological status
• Death

For some outcome measures, it will not necessarily be possible to determine whether they are an inferior degree of cure or sequela after treatment.
5. AIMS OF THE STUDY

*Paper I:*
To study the epidemiology of traumatic CS-fx in the Southeast Norwegian population, based on a prospective registration of cases.

*Paper II:*
To study the epidemiology of traumatic CSI in the complete Norwegian population based on data from the Norwegian Patient Register (NPR).

*Paper III:*
To study surgical complications and long-term outcomes after surgery for traumatic odontoid fractures.

*Paper IV:*
To study surgical complications and long-term outcomes after surgery for S-CS-fx.

6. MATERIALS AND METHODS

6.1 Ethics
Data collection for papers I, III and IV was approved by the data protection official at Oslo University Hospital. Informed consent was obtained from all patients. Data were saved according to instructions of the data protection official.
The NPR is responsible for de-identifying and ensuring the anonymity of the personal data that are released in accordance with the provisions detailed in the applicable laws and regulations. The data analysis file from NPR for paper II did not contain any information that could be traced to specific subjects. The use of such anonymous research files does not require regulatory ethics approval in Norway.

6.2 Materials and methods

Paper I

We prospectively registered all CS-fx patients (C0/C1 to C7/Th1) diagnosed with CCT in Southeast Norway from April 2010 to April 2011 in an observational cohort study. Oslo University Hospital (OUS) is the only hospital that performs open surgery for traumatic CS-fx within this region, and thus all CS-fx patients are either admitted to OUS, or the patient images and charts are referred to us from local hospitals for consultation regarding conservative treatment. In our defined population of 2.7 million people (Southeast Norway 2010), we prospectively registered 319 patients with one or more CS-fx during the year of registration. Based on patient imaging and charts, we registered the demographic data, trauma mechanism, level and classification of injury, neurological status, concomitant head and lower spine injuries, and treatment modality. The vital status (dead or alive) and time of death were obtained from the Norwegian Population Registry (Folkeregisteret) data one year after concluding the patient registration.

Paper II

Using data from the NPR, we obtained access to relevant clinical and demographic information from all government-owned hospitals and outpatient clinics in the country. These data include the hospitalization and discharge dates, patient demographics, diagnostic codes,
and procedures and level of care codes (inpatient/outpatient). The diagnoses and procedures are coded according to the ICD-10 and the NOMESCO Classification of Surgical Procedures, respectively. Updated information on the date of death is included through routine linkage to the Norwegian Population Registry.

To retrieve information on all traumatic cervical spine injuries, including both CS-fx and severe non-fracture cervical spine injuries, we used the appropriate ICD-10 diagnosis to select all traumatic CS-fx, DLC rupture and cSCI episodes that occurred from 2008 to 2012. Because DLC injury covers a broad range of conditions, DLC cases without relevant surgical procedure codes were excluded to ensure that the data set only included truly severe injuries.

Throughout the study period, a total of 10,376 episodes were identified in 4,175 patients. Personal identifiers were available for 97.6% of these episodes. In cases lacking personal identification numbers, the NPR routinely uses a patient number that is unique to each patient within the hospital and year as a substitute.

The data in the NPR do not distinguish between the initial and later treatments for the same condition. To obtain incidence estimates, all the data for patients who were first registered in 2008 (n=927) were excluded from the data set. Thus, the study population included 3,248 patients who were registered with traumatic cervical spine injuries from 2009 to 2012. No patients were registered more than once throughout the study period.

Using these criteria, the patients identified with traumatic cervical spine injuries had the following characteristics:

- One or more CS-fx or
- Severe non-fracture CSI.

The latter was defined as a DLC injury with an accompanying relevant procedure code for open surgery and/or traumatic cSCI, without a coincidental CS-fx.
We identified 97 patients who were treated surgically for odontoid fracture in our department from 2002 to 2009 using our operation protocols.

The inclusion criteria were

- Trauma patients admitted to OUS between January 2002 and December 2009
- Diagnosed odontoid fractures on cervical CT with 2-D reconstructions in three planes
- Odontoid fractures treated with open surgery

Exclusion criteria were

- Odontoid fractures treated only with external fixation

We recorded variables retrospectively from the patient charts. The variables were demographics, trauma mechanism, concomitant head and other spine injury, neurological status pre- and postoperatively, primary intention to treat, timing of surgery and surgical approach and technique, need of re-surgery/cause, thromboembolic complications, and surgical mortality within 30 days. We reviewed the radiological examinations for classification and further description of the fracture patterns.

Vital status (dead or alive), time of death, and whether the patients were living in Norway were obtained from the Norwegian Population Registry one year after inclusion. Of the 68 live patients living in Norway, 8 rejected the invitation to participate in the follow-up examinations and 3 did not respond. Thus, 57 patients were available for follow-up evaluations in 2010 (clinical examination and CCT). At the follow-up, we recorded the time from surgery, neurological status, neck stiffness, neck pain, bony fusion on CCT, pathological movement on flexion-extension radiographs in those lacking bony fusion on CCT, and quality of life using the Short Form-12 Health Survey.

OUS is the largest trauma center in Norway, with a defined catchment area of 2.7 million people (2010), and the hospital performs >95% of open fixations for odontoid fractures within
this patient population, providing the opportunity to estimate an annual incidence of open fixation of odontoid fractures.

*Paper IV*

We identified patients by using the operation list in our department with the following inclusion criteria:

- Trauma patients admitted to OUS between January 2002 and December 2010
- Diagnosed S-CS-fx on CCT with 2-D reconstruction in three planes
- S-CS-fx treated with open fixation surgery

We excluded patients with the following criteria:

- S-CS-fx fractures treated non-surgically
- Ankylosing spondylitis (Mb Bechterew)
- Neoplastic fractures

We found 303 patients matching the criteria. By retrospective chart review, we registered variables for demographics, trauma mechanism, concomitant head and other spine injury, neurological status before and after surgery, primary intention to treat (conservative or surgical), time from injury to surgery, surgical approach and technique, need of re-surgery and cause, and surgical mortality within 30 days. By reviewing the radiological exams, we registered level(s) of injury and classification of injury by SLIC.\textsuperscript{118}

Vital status (dead or alive), time of death, and whether the patients were still living in Norway were obtained from the Norwegian Population Registry two years after inclusion. At this time, 258 patients were alive and living in Norway, 25 were dead and 20 were not found in the Norwegian Population Registry (they were living outside Norway and not available for follow-up).
Of the 258 alive patients living in Norway, two rejected the invitation to participate in follow-up examinations. Thus, 256/258 (99%) of the alive Norwegian patients met for follow-up evaluations from 2010 to 2012 (clinical examination and CCT).

At the follow-up assessment, we registered the time spent from injury, neurological status, neck pain, neck stiffness, hoarseness, and swallowing difficulties. Based on the follow-up CCT, we registered the bony healing of fracture lines, altered position/fracture of the fixation material/graft, pseudarthrosis, and secondary loss of alignment. We defined stable fusion as healed fracture lines, lasting alignment, and no dislocation or failure of the hardware.

7. SYNOPTIC OF THE RESULTS

7.1 Paper I: The epidemiology of traumatic cervical spine fractures; a prospective population study from Norway.

_Aim:_ The aim of this study was to estimate the incidence of traumatic CS-fx in a general population.

_Background:_ The incidence of CS-fx in the general population is largely unknown.

_Methods:_ All CS-fx (C0/C1 to C7/Th1) patients diagnosed with CCT in Southeast Norway (2.7 million inhabitants) during the time period from April 2010 to April 2011 were prospectively registered in this observational cohort study.

_Results:_ Over a one-year period, 319 patients with CS-fx at one or more levels were registered, constituting an estimated incidence of 11.8/100,000/year. The median age of the patients was 56 years (range 4-101 years), and 68% were males. The relative incidence of CS-fx increased significantly with age. The trauma mechanisms were falls in 60%, motorized vehicle accidents in 21%, bicycling in 8%, diving in 4% and others in 7% of patients.
Neurological status was normal in 79%, 5% had a radiculopathy, 8% had an incomplete SCI, 2% had a complete SCI, and neurological function could not be determined in 6%. The mortality rates after 1 and 3 months were 7 and 9%, respectively. Among 319 patients, 26.6% were treated with open surgery, 68.7% were treated with external immobilization with a stiff collar, and 4.7% were considered stable and not in need of any specific treatment. The estimated incidence of surgically treated CS-fx in our population was 3.1/100,000/year.

Conclusions: This study estimates the incidence of traumatic CS-fx in a general Norwegian population to be 11.8/100,000/year. A male predominance was observed, and the incidence increased with increasing age. Falls were the most common trauma mechanism, and SCI was observed in 10%. The 1- and 3-month mortality rates were 7 and 9%, respectively. The incidence of open surgery for the fixation of CS-fx in this population was 3.1/100,000/year.


Background: The incidence of CS-fx in the general population has been sparingly assessed. The aim of the current study was to estimate the incidence of traumatic CS-fx and of open surgery of CSI in the Norwegian population.

Methods: NPR is an administrative database that contains activity data from all Norwegian government-owned hospitals and outpatient clinics. The diagnoses and procedures are coded according to the ICD-10 and the NOMESCO Classification of Surgical Procedures, respectively. We retrieved information on all severe traumatic cervical spine injuries between 2009 and 2012 from the NPR. Updated information on the date of death is included through routine linkage to the Norwegian Population Registry.

Results: Between 2009 and 2012, a total of 3 248 patients met our criteria for severe traumatic CSI. A total of 2 963 patients had one or more CS-fx, and 285 had severe non-fracture CSI.
The median age was 54 years, and 69% of the patients were male. The incidence of CS-fx and severe non-fracture injuries in the total Norwegian population was 16.5/100,000/year, and the incidence of CS-fx was 15.0/100,000/year. A total of 18% of the patients were treated with open surgery, resulting in an estimated incidence of surgery for acute traumatic cervical spine injury of 3.0/100,000/ year in the Norwegian population. The 1- and 3-month mortality rates were 4% and 6%, respectively.

7.3 Paper III: Surgical management of acute odontoid fractures: surgery-related complications and long-term outcomes in a consecutive series of 97 patients.

Background: The purpose of this study was to determine the incidence of surgery for odontoid fractures and to study surgical mortality, surgical morbidity and long-term outcomes in a large, contemporary, consecutive, single institution, surgical series of odontoid fractures.

Methods: This study is a retrospective study of all odontoid fractures treated with open surgery at our hospital from 2002 to 2009. The fractures were classified according to Grauer. Follow-up data, clinical examinations and CCTs were collected in 2010.

Results: This study included 97 consecutive patients with a median age of 73.0 years. The incidence of open fixation of odontoid fractures in this population was 0.45 per 100,000, and the incidence increased with age. The fractures were classified as Type IIA in 3 patients, Type IIB in 63 patients, Type IIC in 8 patients and Type III in 23 patients. Anterior fixation and posterior fixation were performed in 41 and 56 patients, respectively. Immediate postoperative neurological status was unchanged or improved in 97% of the patients. None of the patients developed postoperative hematoma, wound infection, deep venous thrombosis or pulmonary embolism. Eleven patients underwent re-surgery during the follow-up period; five had suboptimal reposition after the first surgery, one had a suboptimal position of an anterior odontoid screw, two had rupture of fixation materials, and three developed pseudarthrosis.
Overall survival (OS) rates after 1, 12 and 24 months were 96%, 84% and 75%, respectively. Fifty-seven patients were available for follow-up evaluation with a mean time of 37 months. Radiological follow-up showed definite bony fusion in 82% of the patients and uncertain bony fusion in 18% of the patients. Flexion-extension radiographs were obtained in six of the ten patients with uncertain bony fusion; five of these were defined as stable (fibrous union), and one was unstable. Multivariate logistic regression demonstrated an increased odds of non-bony fusion in more displaced fractures (OR 1.44, 95% CI (1.04-2.16), \( p = 0.04 \)) and when using the anterior fusion technique (OR 0.17, 95% CI (0.03-0.75), \( p = 0.02 \)). There was no significant association between neck pain and the fusion method (Mann-Whitney test, \( p = 0.86 \)). Patients treated with a posterior fusion approach reported significantly more neck stiffness than patients who underwent fusion with an anterior odontoid screw (Fisher test, \( p = 0.04 \)).

**Conclusions:** The annual incidence of open fixation of odontoid fractures was 0.45 per 100,000 inhabitants, and the incidence increased with age. Median age at time of surgery was 73.0 years, and the surgical mortality was 4%. Increased odds of non-bony fusion were observed in more displaced fractures and after anterior screw fixations. There were no significant differences between patients treated with anterior screw fixation versus posterior wiring with respect to neck pain, but patients fused with a posterior approach reported significantly more neck stiffness.

**7.4 Paper IV: Complications and long-term outcomes after open surgery for traumatic subaxial cervical spine fractures: a consecutive series of 303 patients.**

**Background:** The majority of S-CS-fx are treated non-surgically. Patient selection for surgical treatment can be challenging and depends on fracture morphology, integrity of the DLC, neurological status, co-morbidity, risks of surgery and expected long-term outcomes.
Objective: To evaluate complications and long-term outcomes in a consecutive series of 303 patients with S-CS-fx treated with open surgical fixation.

Methods: This study is a retrospective study of all S-CS-fx treated by open surgery at our hospital from 2002 to 2010. Patients with ankylosing spondylitis were excluded from this study. Medical charts were retrospectively reviewed. Surviving patients participated in a prospective long-term follow-up including clinical history, physical examination and updated CCT from 2010 to 2012.

Results: The median age was 48 years (range 14.7 – 93.9), and 74% of the patients were males. Preoperatively, 43% had SCI and 27% exhibited isolated radiculopathy. Median time from injury to surgery was 2 days (range 0-136). The risk of SCI deterioration and new onset radiculopathy after surgery was 2.0% and 1.3%, respectively. Surgical mortality (death within 30 days after surgery) was 2.3%. These patients were all ≥80 years or had a severe head injury. The reoperation rate was 7.3%. At the long-term follow-up conducted at a median of 2.6 years after trauma (range 0.5-9.1), 256 (99.2%) of the alive patients living in Norway participated. Of the patients with ASIA A-D at presentation, 51% had improved one or more AISA grade. At the time of follow-up, symptoms were absent in 89% of the patients with a preoperative radiculopathy. Furthermore, 11% of the patients reported severe neck stiffness, 5% reported severe neck pain (VAS ≥7), 6% reported hoarseness, and 9% reported dysphagia at the follow-up assessment. The stable fusion rate, as evaluated on CCT, was 98%.

Conclusions: In this large consecutive series of patients with S-CS-fx treated with open surgical fixation, surgical mortality was 2.3%, risk of neurological deterioration was 3.3% and the reoperation rate (any cause) was 7.3%. The long-term results regarding neurology were good, with 51% improvement in the AISA grade and resolution of radiculopathy in 89% of the patients. Stable fusion was excellent at 98%.
8. GENERAL DISCUSSION

8.1 Epidemiology

Prior to our publications, the majority of articles concerning the topic of CS-fx epidemiology has been based on subpopulations, such as trauma center patients, specific age groups, head injury patients, military populations, and patients with specific trauma patterns. We identified three articles from which we could estimate the incidence of traumatic CS-fx in general populations, ranging from 3.6 to 12.0/100,000/year. It is important to determine the epidemiology of CSI in the general population in terms of health-care planning and as a basis for preventive measures.

Norway is a strictly regulated country with relatively few inhabitants, and it has a free public health-care service for all severe trauma, including CSI. All CSI in need of surgery are treated in four neurosurgical departments, one in each of the four health regions. This uniform health-care organization provides a unique opportunity to conduct epidemiological surveys in our country. Additionally, the NPR is available, which is an administrative database in which all patient treatments nation-wide are mandatorily reported.

Our epidemiological study from Southeast Norway estimated a lower incidence of CS-fx compared with that found in the nationwide databases (11.8 versus 15.0/100,000/year). This difference was not unexpected to us. Although the local orthopedic departments within our region refer radiological examinations and clinical details on the gross majority of CS-fx patients to us for treatment planning, we are aware that a minor proportion of the patients are not referred. These might be patients for whom the local treating doctor is convinced that the treatment should be conservative, or patients who are not candidates for surgery because of severe co-morbidities. We are aware of such patients because a few times a year we see
patients who are not registered in our charts, who are referred for a failed conservative treatment of CS-fx. Nonetheless, the Southeast epidemiological study has provided the most detailed information and highly validated data on CS-fx patients because all of the charts and radiological exams were investigated.\textsuperscript{60} The national data registry study offered us what we expect to be the most complete incidence rates of CS-fx.\textsuperscript{196}

The epidemiology of CS-fx will most likely change over time, e.g., due to the increasing number of elderly and an increased awareness of safety measures in road traffic.\textsuperscript{20,37} Increased aging in the population might be expected to lead to an increase in the incidence of CS-fx, and also to a larger proportion of C1 and C2 fractures.\textsuperscript{60,71,197} This again might lead to a more even male:female ratio. Safety measures in road traffic are evolving, technical standards in vehicles are constantly developing, and socioeconomic factors are affecting our purchasing power and thereby our vehicle fleet. In Norway, we see a decreasing number of fatalities in road traffic accidents.\textsuperscript{198} Thus, a larger number of survivors with extensive injuries are to be expected. Safety measures in all aspects of our daily life might also affect the severity of the injuries that occur, including the proportion of concomitant SCI. Measures to prevent fall accidents in the elderly are undergoing trials, including an awareness of medication use and fall risk, and physiotherapy/exercise preventing unsteadiness.\textsuperscript{199} Safety measures and regulation in the workplaces are probably important in terms of preventing injuries.\textsuperscript{200}

The proportion of patients with CS-fx who are treated with open surgery will depend on the development and safety of surgical techniques as well as on our accuracy regarding extraction of the true instability potential of an injury. A further development of MRI techniques and a better understanding of how to interpret the significance of different MRI pathologies are expected to be important in the future. Thus, current epidemiological truths regarding CS-fx incidence, injury patterns, and age and gender distribution cannot be expected to remain valid. \textit{The external validity of the Norwegian epidemiological data.}
Norway is a developed country with a western life-style. We believe that our findings are roughly valid for most developed countries, although some differences in ways of life, the environment, and genetics among countries must be expected. For example, the traffic-related mortality in the United States is significantly higher than that in most other developed countries, and in fact more than three times higher than that in Norway. Other environmental factors may also contribute to geographical differences. We know that the Norwegian population has among the highest hip fracture rates in the world. This is suspected to be caused by a higher rate of osteoporosis, and an inverse association between calcium in the drinking water and hip fracture risk in men has been described. It can be suspected that this phenomenon is transmissible to other fracture patterns, such as CS-fx in the elderly.

8.2 Odontoid fractures

The largest controversies with respect to odontoid fractures include the following questions:

- Which Type II odontoid fractures should be treated surgically?
- What surgical technique is the best?

The primary aim of the paper on surgically treated odontoid fractures was to compare anterior and posterior surgical techniques regarding complications and long-term outcomes. Historically, the technique used in our department for surgical fixation of odontoid fractures has been posterior wiring with a bone graft. The use of anterior screw fixation was gradually implemented and eventually became the preferred technique. Changes in surgical technique are most often driven by enthusiastic entrepreneurs developing a new technique and the technical and equipment driven possibilities more than thorough comparative studies on complications and outcomes. We wanted to explore whether there were differences in complications and outcomes between the two surgical techniques used in our department.
Our main finding was that the differences regarding complications and outcomes between “old” and “new” techniques were small, but it must be kept in mind that this study comprised a relatively small patient population. Overall, the results obtained for both techniques were fairly good, compared with other publications. We learned that the surgical technique should be selected based on the training and familiarity of the surgeon, given the odontoid fracture morphology was suitable for both techniques.

There is no Class I evidence regarding the management of patients with an odontoid fracture,\textsuperscript{77} and the published results are diverging, especially for the elderly with Type II fractures.\textsuperscript{76,197} There are also variations in the definition of the elderly, with 50, 55, 60, 65, 70 and 80 years of age used as a cut-off.\textsuperscript{45,71,76,86,87,90,197} Despite the large number of publications regarding the treatment of Type II odontoid fractures in the elderly, nearly all are class 3 or have a low quality of evidence.\textsuperscript{76,197}

\textit{Union/fusion rate of odontoid fractures Type 2 in the elderly.} A meta-analysis of 29 articles revealed a union rate of 61\% after collar treatment, 59\% after Halo vest, 73\% after anterior screw fixation, and 89\% after posterior fusion.\textsuperscript{197} In our surgical series of odontoid fractures, radiological follow-up revealed definite bony fusion in 82\% of the patients.\textsuperscript{203} Increased odds of non-bony fusion were observed in more displaced fractures and after anterior screw fixations. Even 89\% bony fusion, as found after posterior fusion, is inferior compared with fusion rates after surgery for S-CS-fx.\textsuperscript{204-208} This probably highlights that these geriatric odontoid fractures are at least partly osteoporotic fractures.

\textit{Clinical results of non-union.} Three articles have addressed the functional outcome in elderly survivors after odontoid fracture with respect to fusion/non-fusion.\textsuperscript{209-211} All papers concluded that there were no significant differences in functional outcomes at the time of follow-up with regard to radiographic fusion or non-union. Thus, if the patients survives the first months after traumatic odontoid fracture but does not achieve a bony fusion, then perhaps it does not
mater? The hypothesis is that a fibrous non-bony fusion appears in the majority of patients. Dynamic flexion-extension studies are used to distinguish between fibrous union and pseudarthrosis. However, we do not know the meaning of asymptomatic non-union in terms of biomechanical strength regarding future patient trauma, but it might entail a risk factor.

**Morbidity.** Is surgical treatment associated with more complications in comparison to external immobilization of odontoid fractures Type II in the elderly? Of course, treatment method-related complications will clearly differ, with pressure ulcers associated with collar and Halo-vest treatment, pin-site infections with Halo-vest treatment, dysphagia after anterior approach surgery, infections after posterior surgery, pneumonia after surgery, and vertebral artery injury after posterior screw fixation. However, overall, this question cannot be answered by current evidence. None of the treatment modalities for odontoid fractures in the elderly have been confirmed to be superior with regard to clinically important complications and morbidity.

**Mortality.** Cumulative survival data from 29 articles on elderly patients with odontoid fractures Type II revealed a 20-month longer mean survival in surgically treated versus nonsurgically treated patients. These data were only adjusted for age, not for co-morbidity and other possible confounders, clearly limiting the strength of this result. A large retrospective cohort study also revealed a significant increase in survival in surgically treated patients, and these data were adjusted for confounding factors. In another retrospective cohort examining the survival after surgically or non-surgically treated odontoid fractures Type II, the cohort was subdivided in three age groups. Improved survival with surgery was found in the 65-84-year-old age group, but patients ≥ 85 years of age who were treated surgically showed an increase in mortality.

The management of odontoid fractures in elderly patients is associated with increased failure rates, and higher rates of morbidity and mortality irrespective of the treatment offered.
quality of the data on this topic is generally low.\textsuperscript{76,197} Current knowledge implies that surgical fixation of odontoid fracture Type II in the elderly should be considered, at least up to the age of 85 years.\textsuperscript{76,197} This controversy is also the main controversy regarding odontoid fractures, given the high co-morbidity rates observed in many of these elderly patients (Table 3). Our paper examining surgically treated patients with odontoid fractures could not address complication and outcome differences with conservative and surgical treatment, but our study group includes a large on-going project designed to address this issue.
Table 3. Flow chart with treatment recommendations for Type II and III odontoid fractures.

* This is the main controversy. Many of these patients are elderly and present substantial co-morbidities.
8.3 Subaxial cervical spine fractures

S-CS-fx encompass a broad spectrum of injuries, from less severe injuries for which non-surgical treatment may be employed successfully to life-threatening injuries, which confer a high risk of morbidity. Patient selection for surgical treatment may be demanding. We have implemented the SLIC recommendations, where 0-3 points leads to conservative treatment, ≥5 points lead to surgery, and 4 points results in a treatment that is dependent on the clinician’s considerations. The SLIC morphological classification is almost exclusively based on CCT. In addition, it is of major importance to understand the risks of surgery and the long-term outcomes after surgery when deciding whether to operate.

In our consecutive series of patients with S-CS-fx treated with open surgical fixation, the surgical mortality was 2.3%, the risk of neurological deterioration was 3.3% (SCI 2.0%, radiculopathy 1.3%), and the reoperation rate (any cause) was 7.3%. The long-term results regarding neurologic function were good, with AIS grade improvement in 51% and resolution of radiculopathy in 89% of the patients. Stable fusion was excellent and was achieved in 98% of cases.

A frequent concern in CS-fx treatment decision making is whether we can justify surgical fixation, with its inherent possibilities for complications, in patients in whom the extent of instability is difficult to determine. Considering the high risk of morbidity that may be entailed by S-CS-fx, the surgical risk in our series was considered acceptable. In our opinion, the results support the surgical treatment of patients < 80 years of age when there are substantial doubts concerning whether an injury is sufficiently stable for non-surgical handling.

However, these results does not detour us from the continuous obligation to strive for more accurate treatment decision making, best surgical techniques, correct timing of surgery, minimization of complication rates, and optimization of the non-surgical treatment.
Detection of CSI and treatment decision making have become more accurate with high quality CCT with 2-D reconstructions in three planes, compared to the former plain x-rays.\textsuperscript{50} Regular use of MRI have contributed to our interpretation of stability in CSI, and also in CSI diagnostics in patients with ankylosing spondylitis and pronounced degenerative changes. However, as mentioned previously, there are still unsolved issues regarding how to interpret some of the MRI pathologies in terms of stability. Future goals must include a better accuracy in this regard. Studies investigating patients who are first assigned for non-surgical treatment and later reassigned to surgery because of treatment failure, might also highlight pitfalls in our decision making.

In addition to the knowledge that CSI in patients with ankylosing spondylitis requires a long-segment posterior fixation or a combined anterior-posterior procedure, no consensus or scientific evidence provides definitive guidelines regarding the surgical approach in subaxial CSI.\textsuperscript{127,128} In our series of surgically treated S-CS-fx, there were few or no differences in outcome measures regarding the surgical approach. This result might be due to type 2 errors caused by small subgroups, making it more difficult to detect minor differences. Fixation device failure, malalignment, and/or inadequate decompression were the indications for re-surgery in 5.0% of the patients in our series of S-CS-fx patients treated with surgery. Some of these complications could possibly have been avoided with the use of spinal navigation and/or better quality fluoroscopy in the operating room (OR). The choice of surgical approach might also have been suboptimal in some of the cases and thereby contributed to the adverse result. To ensure an optimal screw placement and realignment is of course always the goal, both for achieving a stable fixation and for avoiding complications. Pedicle screw placement in the subaxial segment is considered a demanding technique, but it might provide an advantage in cases in which a biomechanical optimal fixation is needed. Some authors have presented this technique and documented low rates of instrumentation-related complications.\textsuperscript{216-218} The use
of spinal navigation will likely offer a lower risk of injury to the vertebral artery and spinal cord in this type of surgical technique. Spinal navigation has been implemented in our department during the last year.

Our non-surgical handling of patients with subaxial CSI will always entail a small risk of failed treatment and the need for reassignment to surgery. In most cases, this will be due to an extent of DLC injury in cases of S-CS-fx that has not been acknowledged. We have found that in the majority of patients, this failure is revealed within the first 14 days after injury (unpublished data). We have implemented a one-week follow-up with clinical examination and CCT, with the intent to reveal these cases as early as possible. Other indications for redirection to surgery might be increasing radiculopathy, increasing kyphosis, and pseudarthrosis. These indications can occur over a larger time span and imply the need for additional follow-ups at later time points. Our standardized control routines after CSI in need of external immobilization or surgery are 1, 4 and 12 weeks after the initiation of treatment.

9. CONCLUSIONS

Paper I

- This prospective study estimates the incidence of traumatic CS-fx in a general Norwegian population to be 11.8/100,000/year. A male predominance was observed, and the incidence increased with advancing age. Falls were the most common trauma mechanism, and SCI was observed in 10% of those included. The 1- and 3-month mortality rates were 7% and 9%, respectively. The incidence of open surgical fixation of CS-fx in this population is 3.1/100,000/year.
Paper II

- The incidence of severe traumatic CSI in the general Norwegian population is estimated at 16.5/100,000/year. The incidence of traumatic CS-fx is estimated at 15.0/100,000/year, and the incidence of severe non-fracture cervical spine injury is estimated at 1.5/100,000/year. The incidence of open surgery for acute traumatic CSI is estimated at 3.0/100,000/year. The 1- and 3-month mortality rates were 4% and 6%, respectively. The risk of death within 3 months after CSI was 2% in patients <75 years old and 18% in patients >75 years old. CSI occurred most frequently in the 45- to 89-year age group. When adjusted for age distribution, we found the highest incidence in the oldest age group.

Paper III

- The annual incidence of open fixation of odontoid fractures was 0.45 per 100,000 inhabitants, and the incidence increased with age. The median age at time of surgery was 73.0 years, and the surgical mortality was 4%. An increased likelihood of non-bony fusion was observed for more displaced fractures and after anterior screw fixations. There were no significant differences in treatment outcome between patients treated with anterior screw fixation versus posterior wiring with respect to neck pain, but patients fused with a posterior approach reported significantly more neck stiffness.

Paper IV

- S-CS-fx encompass a broad spectrum of injuries, from less severe injuries for which non-surgical treatment may be employed successfully to life-threatening injuries, which confer a high risk of morbidity. Patient selection for surgical treatment may be demanding, and, thus, it is of major importance to understand the risks of surgery and the long-term outcomes after surgery. In this large consecutive series of patients with S-CS-fx treated with open surgical fixation, the surgical mortality was 2.3%, the risk
of neurological deterioration was 3.3%, and the reoperation rate (any cause) was 7.3%.
The long-term results regarding neurologic function were good, with AISA grade improvement in 51% and resolution of radiculopathy in 89% of the patients. Stable fusion was excellent and was achieved in 98% of cases. Considering the high risk of morbidity related to S-CS-fx, the surgical risk in this series is considered acceptable.

10. FUTURE ASPECTS

- As mentioned previously, there are constant changes in the population composition as well as in personal life-styles and societal patterns. Updated knowledge of the epidemiology of CS-fx requires revised studies on the subject. Since 2015, our study group has registered all CS-fx in the Southeast Norwegian population in a prospective database. The database will serve as a foundation for future epidemiological and clinical studies.

- Scientific level 1 supported treatment recommendations for odontoid fractures Type 2 in the elderly are still missing. Our study group has a large on-going prospective study comparing complications and long-term outcomes after conservative and surgical treatment of odontoid fractures.

- There are still unsolved issues regarding how to interpret some of the MRI pathologies in terms of stability. The goal for the future must be an improved accuracy in this regard. This might be achieved by developing new MRI techniques, or large studies comparing unsettled MRI findings with the clinical course and/or perioperative findings regarding the DCL status/biomechanics.
• Spinal navigation has been implemented in our department over the last year. Our clinical experience to date implies that this might be a useful tool for minimizing surgical risks and allowing us to expand our surgical repertory for more stable screw constructions. Our study group has initiated a prospective study examining outcomes after fixations aided by spinal navigation.

• We are continuously striving to improve our follow-up programs, aiming to achieve the most appropriate control routines for the defined targets of the follow-up. Based on patient reviews (unpublished data), we have changed the frequency of our follow-ups in recent years.

• There is no consensus in the literature regarding the duration of treatment for CS-fx patients treated with external immobilization. Communications with both national and international centers suggest significant variations. In our department, we have traditionally treated patients with bracing for 12 weeks. Our study group has an ongoing clinical study randomizing patients with S-CS-fx who do not require surgery to 6 or 12 weeks of external immobilization with a collar.

• In 2012, Norsk Ryggmargssregister was authorized as a medical quality register; and in 2014, Norsk Ryggmargsskadeforskning Stiftelse was established. The aim of both institutions is to promote research for SCI patients regarding improved acute treatment and rehabilitation programs.

• Stem cell therapy for SCI has been a research topic for the last decades, and there are increasing numbers of human trial reports. A review from 2015 concluded, based on 24 available publications examining bone marrow-derived cells, that stem transplantation appears to be safe and valid in SCI patients according to short-medium-term follow-ups. The major outcomes of the summarized AISA improvement rate suggested that bone marrow-derived transplantation has the potential to improve
the function of SCI patients, which is most promising for complete and chronic SCI. However, there were no significant differences in secondary outcomes. The overall quality of the publications was rated low, and prospective, randomized trials conducted in larger cohorts are still needed.219
11. REFERENCE LIST


Errata liste

Navn kandidat: Hege Linnerud Fredø

Avhandlingstitel: Epidemiology and Surgery in Traumatic Cervical Spine Fractures

Forkortelse for type rettelse: Cor=korreksjon. Celtf= endring av sidelayout eller tekstformat

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