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CERVICAL SPINE INJURIES IN ADULTS: DIAGNOSTIC IMAGING AND TREATMENT OPTIONS

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Academic Dissertation

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CONTENTS

ABSTRACT

Cervical spine injuries occur at an annual incidence of 210 per million, causing annually 8 to 21 spinal cord injuries per million. Motor vehicle accidents are the most common trauma mechanism, with 3:1 male predominance. Despite being relatively rare—occurring in only 2.4% of blunt trauma admissions—the social and economic impact of cervical spine injuries is extensive, because the majority of cervical spine injuries complicated by spinal cord injury occur in young adults, with median age of only 31 years, often with life-long consequences.

Knowledge of epidemiology, biomechanics, both cell-level and macroscopic pathology, and surgical techniques in cervical spine injuries is constantly growing in the midst of an explosion of technical advances in diagnostic imaging and surgical instrumentation. This thesis focused on surgical and conservative treatment of subaxial cervical spine fractures, on conservative treatment failure in type II odontoid process fractures, on comminuted odontoid process fractures, and on the diagnostic imaging of cervical spine fractures complicating ankylosing spondylitis.

These results show that in flexion teardrop and burst fractures, anterior surgical decompression, bone grafting, and stabilization provide—compared to conservative treatment—a superior restoration of the spinal canal which will promote neurological recovery. Similarly, in fracture dislocations, posterior surgical stabilization resulted in better anatomic end results. Appropriate reduction of dislocations correlated with neurological recovery. Late neck pain is related to residual displacement and is more common after conservative treatment. Complication rates of both anterior and posterior surgery were as low as with conservative treatment. The results also show that in odontoid process type II fractures, bony union following a halo vest treatment is unlikely in the presence of a fracture gap > 1 mm, posterior displacement > 5 mm, posterior re-displacement > 2 mm or delayed start of treatment > 4 days. Subtle comminution of type II fractures is, based on multi-detector computed tomography, significantly more common than previously described. The results also show that in advanced ankylosing spondylitis, multi-detector computed tomography is superior to plain radiography or magnetic resonance imaging in detection and characterization of cervical spine fractures.

In conclusion, the transition from conservative treatment to anterior surgery for burst and flexion teardrop fractures and to posterior surgery for fracture dislocations has resulted in superior anatomic results promoting neurological recovery. In type II odontoid process fractures, patients who are unlikely to achieve bony union by halo vest may be identified. Subtle comminution is relatively common among these fractures. And finally, multi-detector computed tomography is the method of choice in suspected cervical spine injury complicating ankylosing spondylitis.

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following articles, which are referred to in the text by their Roman numerals I–V:

I Koivikko MP, Myllynen P, Karjalainen M, Vornanen M, Santavirta S. Conservative and operative treatment in cervical burst fractures. Arch Orthop Trauma Surg 2000; 120:448–451.

II Koivikko MP, Myllynen P, Santavirta S. Fracture dislocations of the cervical spine: a review of 106 conservatively and operatively treated patients. Eur Spine J 2004; 13:610–616.

III Koivikko MP, Kiuru MJ, Koskinen SK, Myllynen P, Santavirta S, Kivisaari L. Factors associated with nonunion in conservatively-treated type-II fractures of the odontoid process. J Bone Joint Surg [Br] 2004; 86:1146–1151.

IV Koivikko MP, Kiuru MJ, Koskinen SK. Occurrence of comminution (type IIA) in type II odontoid process fractures: a multi-slice CT study. Emerg Radiol 2003; 10:84–86.

V Koivikko MP, Kiuru MJ, Koskinen SK. Multidetector Computed Tomography of Cervical Spine Fractures in Ankylosing Spondylitis. Acta Radiol 2004; 45:751–759.

Permission for reprinting was requested from the publishers.

ABBREVIATIONS

ALL	Anterior longitudinal ligament
AS	Ankylosing spondylitis
CSI	Cervical spine injury
CT	Computed tomography
GCS	Glasgow Coma Scale
HTV	Halo-thoracic vest
ICD	International Statistical Classification of Diseases and Related Health Problems
MDCT	Multi-detector computed tomography; multi-slice computed tomography
MPR	Multiplanar reformation
MRI	Magnetic resonance imaging
MVA	Motor vehicle accident
NEXUS	National Emergency X-radiography Utilization Study
PACS	Picture archiving and communication system
PLL	Posterior longitudinal ligament
ROM	Range of motion
SCI	Spinal cord injury
SCIWORA	Spinal cord injury without radiographic abnormality
SEH	Spinal epidural hematoma
STIR	Short time to inversion recovery; short tau inversion recovery
T1	Longitudinal relaxation
T2	Transverse relaxation
T2*	Transverse relaxation obtained using gradient echo sequences
VBS	Vertebral body sagittal distance

INTRODUCTION

"Instructions concerning a crushed vertebra in his neck. If thou examinest a man having a crushed vertebra in his neck thou findest that one vertebra has fallen into the next one, while he is voiceless and cannot speak; his head falling downwards, has caused that one vertebra crush into the next one; and shouldest thou find that he is unconscious of his two arms and his two legs because of it. Thou shouldest say concerning him `One having a crushed vertebra in his neck; he is unconscious of his two arms and his two legs and he is speechless. An ailment not to be treated'."

Edwin Smith papyrus

These are the first known instructions regarding treatment options for spinal cord injury (SCI) in acute cervical spine injury (CSI); it dates from Egypt in approximately 2500 BC (Sanan and Rengachary 1996). The original author is not known for certain, but some believe that Imhotep, physician at the court of Pharaoh Zoser of the Third Dynasty, was at least one co-author of the text. Ancient Egyptian knowledge of anatomy—advanced by the examination of the dead in the mummification process—was relatively well developed. It is remarkable that the difference between simple fractures, subluxations, and neurologically complicated fracture dislocations was well appreciated by then, as was the association between burst fractures and their causative axial loading injury mechanism (Sanan and Rengachary 1996, Goodrich 2004). Some 2000 years later, the optimal methods for closed repositioning of thoracolumbar fractures and scoliosis were debated in Greek. Hippocrates (460–361 BC) condemned "succussion", i.e., upside-down hanging of patients by ropes strapped to their ankles, a public spectacle performed in city centers. Instead, he recommended straps from both arms and legs to be attached to winches and, once the dislocation was distracted, repositioning of the vertebrae manually or ideally, by use of levers. Succussion was, however, a well established treatment of choice by then and remained in use until the

15th century AD. Hippocrates also discussed theoretical possibilities of anterior open reduction of dislocations, but still favored conservative treatment (Goodrich 2004).

Galen (131–201 AD) described several of the cervical spine ligaments, correlated the segmental level of an SCI with upper extremity motor and sensory dysfunction and also proposed the idea of removing the posterior vertebral arch in order to decompress the marrow. Paul of Aegina was the first to actually do this, in the seventh century AD. Leonardo da Vinci (1452–1519) contributed not only by describing spinal anatomy, but also by studying the basic concepts of spine biomechanics. Vesalius (1514–1564) studied spinal anatomy in even greater detail, correcting inaccuracies of Galen and da Vinci. Giovanni Alfonso Borelli (1608–1679) described biomechanics of the spine in impressive detail and was able accurately to calculate loads sustained by individual vertebrae and intervertebral disks.

Fabricus Hildanus described in 1646 repositioning of cervical spine dislocations with tongs and an interspinous needle. Leonhard Euler introduced in 1744 the concept of spinal stability, which would turn unstable at a known point he described as a “critical load.” The first internal fixation, posterior interspinous wiring, was described by Hadra in 1891, modern skull traction in 1929 (Taylor 1929), and skull traction by tongs in 1933 (Crutchfield 1933). Since then, both external and internal stabilization methods have undergone constant development, with posterior interspinous fixation refined by Rogers in 1942, introduction of anterior surgery (Bohler 1967), and the halo-thoracic vest (HTV, Perry and Nickel 1959). These were followed by the numerous selection of internal and external stabilization methods used presently (Omeis et al. 2004, Moftakhar and Trost 2004). Unstable CSIs are a heterogeneous group of dissimilar injuries. Each has a specific optimal treatment, but because each is also relatively rare and often complicated by SCI, leading to issues of ethics, it is not surprising that randomized trials comparing the efficiency of treatments have remained few—leading to controversy regarding optimal treatment.

REVIEW OF THE LITERATURE

Classification and etiology of CSI

While several classification systems for CSI co-exist, none of them has gained uniform acceptance among researchers or clinicians. CSI can be classified according to injury level, trauma mechanism (Allen et al. 1982, Harris et al. 1986), morphology (Bohlman 1979), or instability of the fracture. As the exact trauma mechanism in a CSI often remains uncertain, even classifications based on trauma mechanism rely, to some extent, on morphologic patterns of the injury; the trauma mechanism is indirectly determined from radiological findings. The complexity of some CSIs indicates the presence of several different injury mechanisms in a single trauma (Cusick et al. 1996). Assessment of spinal stability and instability are essential in conjunction with all classification systems, as choice of treatment in each specific type of CSI is based on whether the injury is considered biomechanically and clinically stable or not. Classification by injury level to upper (C0–2) and lower (C3–7) CSI is well established, because the anatomical and biomechanical properties—and thus also the type and significance of injuries—of the two uppermost cervical vertebra significantly differ from those in the third to seventh vertebra. In most studies and also clinically, a combination of several classification methods is used concurrently. For example, the injury is described by both level and trauma mechanism followed by morphological description of the injury and finally an assessment of stability (Figure 1).

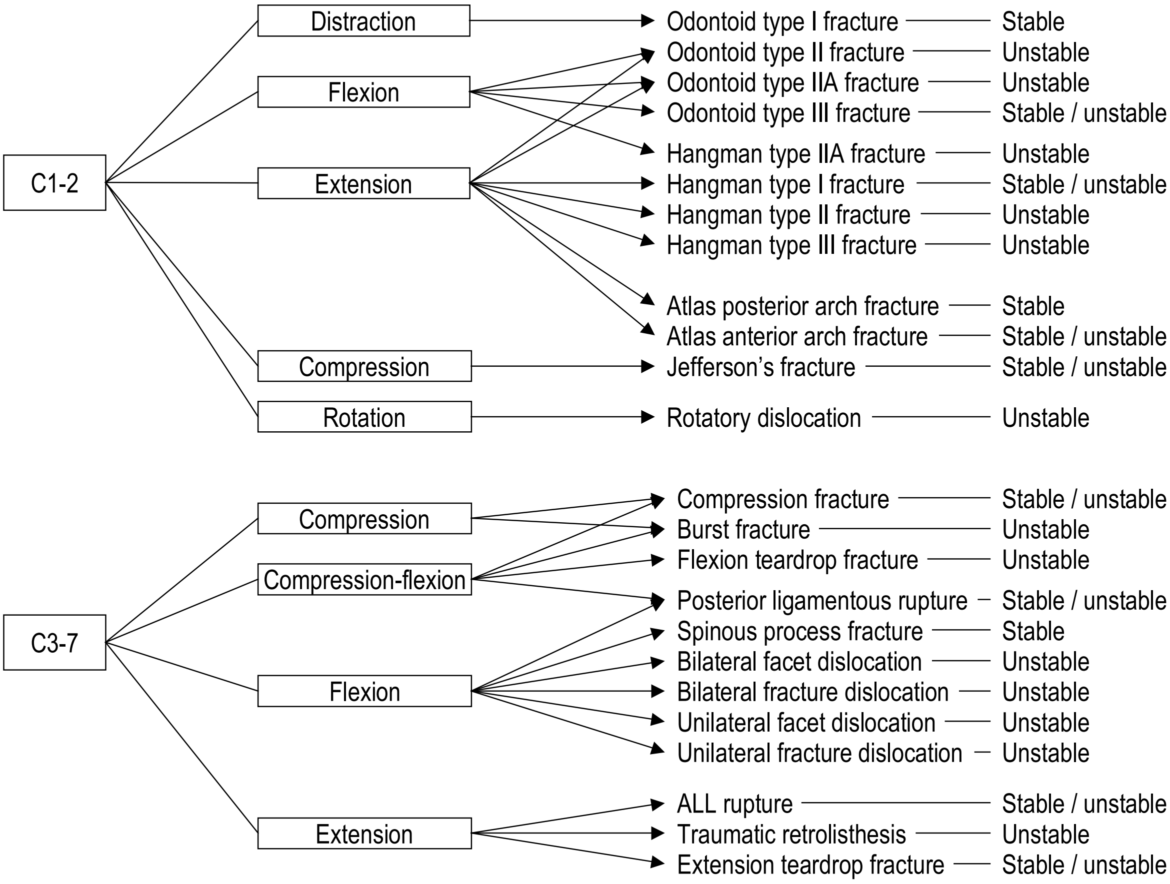

Figure 1. Classification of some CSIs by level, trauma mechanism, and morphology, and resultant clinical stability. In clinical practice, great care is required to assess the stability of each injury individually.

Anatomy, biomechanics, and instability

The cervical spine is a relatively complex anatomical structure consisting of seven slightly differing vertebra with a total of 23 articulations: two C0/1 facet joints, two C1/2 facet joints plus the odontoid process articulation with the C1 anterior arch, and two facet joints plus an intervertebral disk in each of the C2/3 to C7/Th1 segments. Movements of the cervical spine are, in addition to active (and clinically probably insignificant) stabilization by muscle contraction, also passively restricted by facet joints, anterior (ALL) and posterior (PLL) longitudinal ligaments, intervertebral disks, ligamentum flavum, facet joint capsules, and intertransverse, interspinous, and supraspinous ligmaments, as well as ligamentum nuchae. Flexion is restricted mainly by the posterior ligaments (White et al. 1975, Johnson et al. 1975), i.e., by ligamentum flavum, by interspinous, supraspinous, and nuchal ligaments, and by facet joint capsules (Zdeblick et al. 1993). Extension is restricted by ALL, PLL, and the intervertebral disks (White et al. 1975, Johnson et al. 1975). In addition to the intervertebral disk and facet joint capsules, the frail intertransverse ligaments restrict lateral bending (Johnson et al. 1975). Rotation is restricted by the intervertebral disk and to some extent by the tensile force of all the other ligaments. Rotatory restriction by the facet joint capsule is less significant (Zdeblick et al. 1993). The facet joints effectively restrict anterior translatory movement (White et al. 1975). In the upper cervical spine, the tectorial membrane, and the cruciform and alar ligaments provide additional stability; the anterior atlanto-occipital membrane is an extension of ALL. The transverse ligament, which is the horizontal part of the cruciform ligament, is the primary ligamentous stabilizer of the C0/1 segment and prevents anterior movement of the C1 ring, allowing it to pivot around the odontoid process. The apical ligament offers no significant stability to the craniocervical junction (Tubbs et al. 2000). Accessory atlanto-axial ligaments running laterally within the osseous spinal canal are common and provide additional rotational stability (Tubbs et al. 2004).

The main movement of the C0/1 segment is flexion-extension (average range of motion, ROM 25∀) while rotatory and lateral bending movements (10∀ ROM each) of this segment are minor (White and Panjabi 1990). The C1/2 segment has, on average, a 20∀ ROM in flexion-extension, only minor lateral bending (ROM 10∀) and an important rotatory function (ROM 80∀), contributing approximately half of the rotatory movement of the whole cervical spine. The C2/3 segment has a 10∀flexion-extension ROM, a 20∀ lateral bending ROM, and only a 6∀rotational ROM. C3/4, C4/5, and C5/6 share similar motion characteristics: on average a 15–20∀flexion-extension ROM, a 16–22∀lateral bending ROM, and a 14∀rotational ROM. In contrast, the C6/7 and C7/Th1 segments are relatively rigid: on average a 6–7∀flexion-extension ROM, a 8–14∀lateral bending ROM, and rotationally a 12∀ROM in C6/7 and only 4∀in C7/Th1. With advanced age, the rotation of the C1–2 segment slightly increases, while the overall cervical spine mobility in flexion-extension, lateral bending, and rotation decreases with age (Dvorak et al. 1992) due to degenerative changes of the spine (Dvorak et al. 1993).

No uniformly accepted criteria for instability in CSI exist. Questions arise, whether the criteria of instability should be based on manifest clinical symptoms and findings, and if so, should conditions that could potentially cause such clinical consequences be also considered instability? Or should the assessment of instability rely only on technical evidence of mechanical failure of the normal vertebral relationships such as a measurable change in range of motion exceeding physiological limits or radiological findings demonstrating incompetence of the stabilizing structures? This inconsistency in the literature may lead to unnecessary differences in treatment and thus in reported clinical results, as instability is the generally accepted indication for surgical intervention in CSI. In their biomechanical analysis of subaxial ligamentous injuries, White et al. (1975) defined clinical stability as “the ability of the spine to limit its patterns of displacement under physiologic loads so as not to damage or irritate the spinal cord or the nerve roots.” This became probably the most popular definition of cervical spine stability. Their later refinement of this definition emphasized clinical symptoms in instability: “loss of ability of the spine under physiologic loads to maintain relationships in such a way that there is neither damage nor subsequent irritation to the spinal cord or nerve roots and, in addition, there is no development of incapacitating deformity or pain” (White and Panjabi 1990).

In lower cervical spine injuries, biomechanical cadaver studies have significantly contributed to the understanding of the mechanisms of traumatic instability (Cusick and

Yoganandan 2002). Progressive removal—either anterior or posterior—of ligamentous structures does not result in progressively increasing ROM. White et al. (1975) found that cervical spines with intact anterior structures plus one posterior element, or spines with intact posterior structures plus one anterior structure remain biomechanically stable under physiological loads. Any further removal of stabilizing ligaments causes a sudden increase in flexion-extension ROM. In their study, "anterior structures" included PLL and any structures anterior to it, while "posterior structures" were those posterior to PLL. The two-column (Holdsworth 1970) and three-column (Denis 1983) concepts—both initially used in thoracolumbar injuries and later also used in CSI—essentially evaluate the same stabilizing structures and share similar biomechanical assumptions (Figure 2). White also concluded that 2.7-mm horizontal displacement (3.5 mm in a radiograph, when adjusted for magnification) in a cervical spine motion segment exceeds the normal physiological limits and indicates biomechanical instability (White et al. 1975). Similarly, using adjacent motion segments as the reference, they found an angular displacement of more than 11 degrees indicating biomechanical instability. Applications of computed biomechanical models such as finite element models may in future improve the understanding of injury mechanisms and instability (Brolin and Halldin 2004).

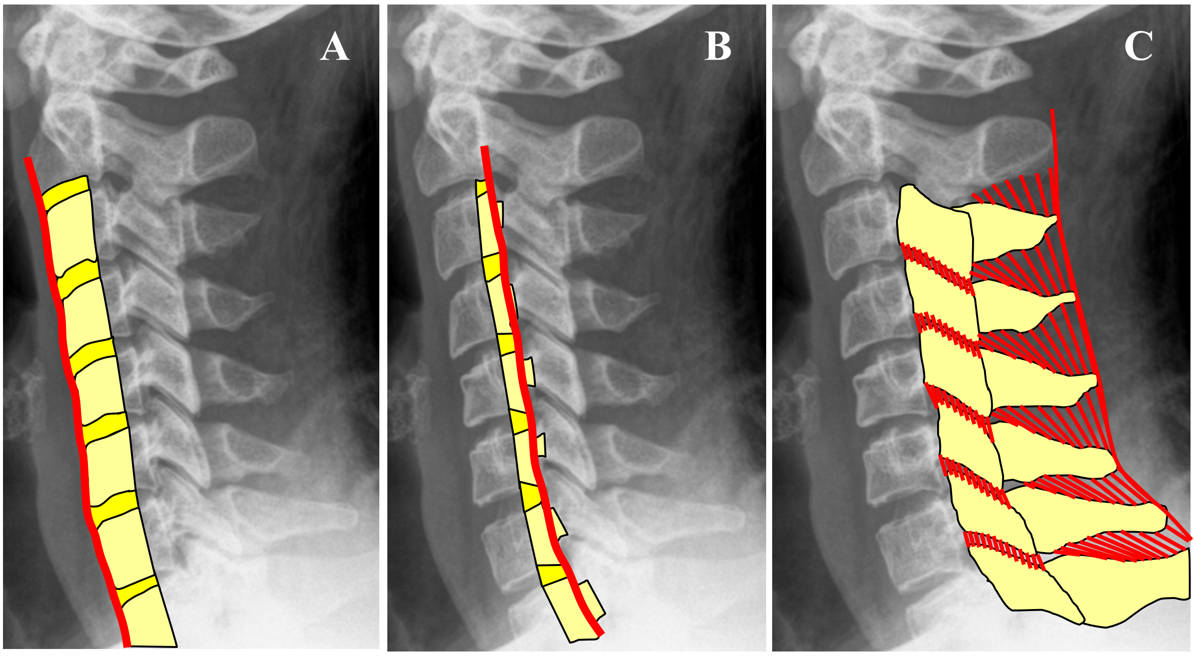

Figure 2. Three-column concept of cervical spine stability: Stabilizing structures divided into three columns. Insufficiency of two or three columns indicates instability, whereas injuries of one column may be stable.

Occipitocervical junction and upper cervical spine (C0–2)

Fractures of the occipital condyles are relatively rare and usually neurologically uncomplicated injuries, yet, by modern imaging, the incidence of these fractures may, especially in high-energy traumatized patients, be considerably higher than previously appreciated (Capuano et al. 2004). Atlanto-occipital (C0/1) dislocations (Figure 3) are encountered clinically only rarely (Goldberg et al. 2001), as they are associated with a very high mortality before hospitalization. Even after hospitalization they show an approximately 50% mortality (Labler et al. 2004).

Atlas (C1) fractures account for 8.8% of CSI in blunt trauma. While the injury may be limited to the anterior arch (13%), posterior arch (18%), or lateral mass (21%) only, which are considered relatively stable injuries, the most common injury pattern (37%) is a comminuted fracture of both the anterior and the posterior arch (Goldberg et al. 2001). The most common of such comminuted injury patterns, Jefferson's fracture (Figure 4), is a compression fracture of C1 with bilateral fracture lines in both the anterior and posterior arches. The hallmark finding in this injury is the tendency of the lateral masses to migrate laterally. In the past, integrity of the transverse ligament was indirectly interpreted from radiographs: In stable type I fractures the net displacement of the lateral masses is less than 7 mm and in unstable type II fractures—with a torn or avulsed transverse ligament—more than 7 mm (Spence et al. 1970). Magnetic resonance imaging (MRI) can show transverse ligament ruptures and avulsions more reliably and thus provide more precise information on biomechanical stability in these injuries (Dickman et al. 1996). Multiple upper cervical spine injuries, commonly also affecting atlas, are relatively common (Gleizes et al. 2000).

Figure 3. Atlanto-occipital dislocation. Note how innocent the MDCT midline sagittal MPR image (upper left) appears, whereas images through the occipital condyles (upper right) demonstrate a widened atlanto-occipital joint. MRI (lower left) verifies the extensive ligamentous injury. For comparison (lower right), a normal atlanto-occipital junction.

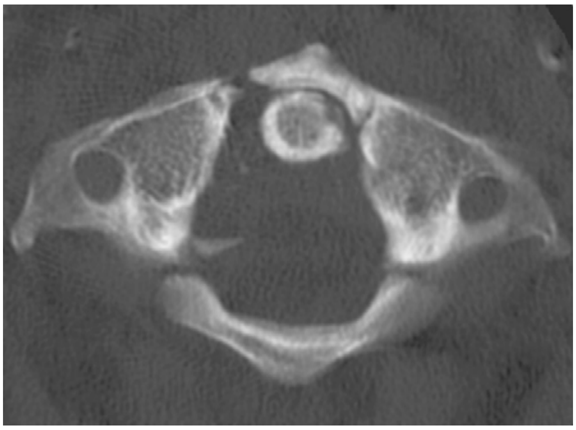

Figure 4. Jefferson's fracture.

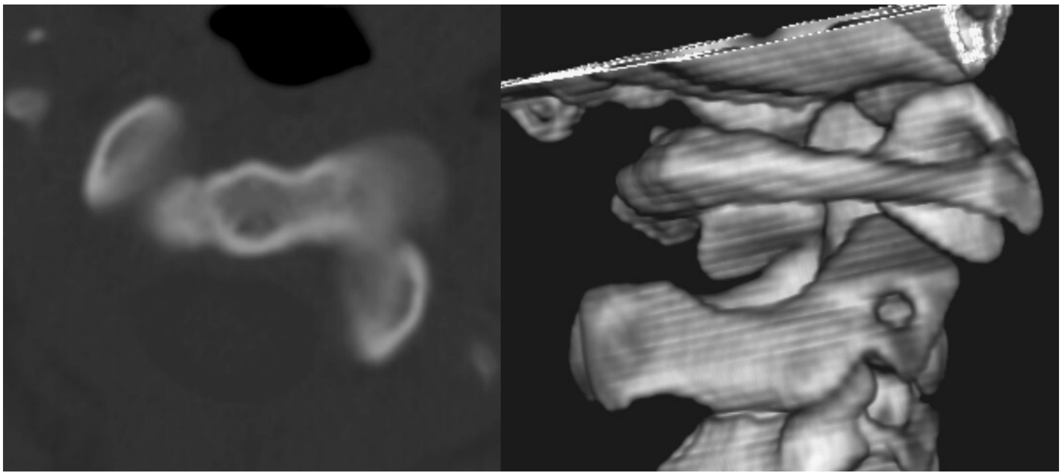

Figure 5. Atlanto-axial rotatory dislocation.

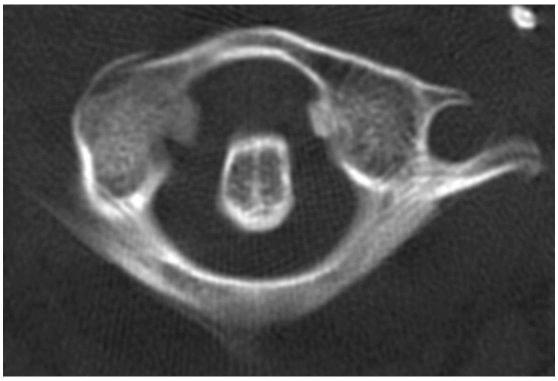

Figure 6. Anterior atlanto-axial dislocation due to transverse ligament rupture.

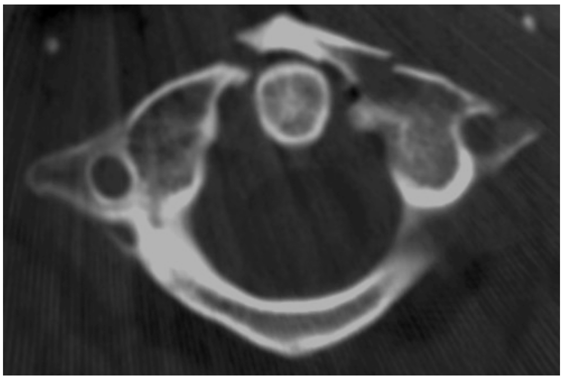

Figure 7. Posterior atlanto-occipital dislocation due to atlas anterior arch fracture.

Atlanto-axial (C1/2) dislocations can occur in three distinct patterns: a rotatory dislocation of the facets, one anteriorly and one posteriorly (Figure 5), an anterior dislocation due to transverse ligament rupture or odontoid process fracture (Figure 6), or a posterior dislocation due to C1 anterior arch fracture (Figure 7) or odontoid process fracture. Fielding classified the rotatory dislocations into four types, based on severity: type I rotatory fixation without subluxation, type II rotatory fixation with unilateral 3 to 5 mm facet dislocation, type III with bilateral facet dislocation greater than 5 mm, and type IV rotatory fixation with bilateral posterior dislocation (Fielding and Hawkins 1977). Type I injuries can occur within physiologic ROM without ligamentous injury, types II and III with ligamentous injuries, and type IV in conjunction with odontoid process insufficiency (fracture, rheumatoid erosions).

The axis (C2) is the most frequently (23.5–23.9%) injured cervical vertebra in blunt trauma (Goldberg et al. 2001, Touger et al. 2002) and relatively more often in patients aged over 65 (Touger et al. 2002). Odontoid process (dens) fractures, which account for 7.7% of CSI and are present in 11% of patients with CSI (Goldberg et al. 2001), are the most common upper CSI. The stable type I (Anderson and D'Alonzo 1974) fractures—alar ligament distractive avulsion of the odontoid tip—account for 5% of odontoid fractures, and the unstable type II fractures—flexion or extension injuries with a fracture of the odontoid base (Figure 8)—for 57% of odontoid fractures. Only a few cases of the proposed type IIA (Hadley et al. 1988) odontoid base fracture, which is comminuted (with additional free fragments at the fractured odontoid base) and thus a very unstable subtype, have been reported (Hadley et al. 1989, Koc et al. 2001). Based on tomography, Hadley et al. (1988) estimated that 5% of odontoid base fractures are type IIA. Type III fractures account for 36% of odontoid fractures (Goldberg et al. 2001), are located in the area of the vertebral body (Figure 9), and are usually considered to be relatively stable injuries

Hangman's fractures, i.e., traumatic spondylolisthesis of the axis account for 9.6% of axis fractures (Goldberg et al. 2001). As with most CSI, several classifications co-exist. The classification proposed by Effendi (1981) has gained the widest acceptance, describing type I injury as a fracture through both pars interarticularis with less than a 3-mm displacement (Figure 10); type II injuries have more than a 3-mm displacement;

and type III injuries have an additional C2/3 facet joint displacement. All three types are believed to result from hyperextension. A later refinement of the classification (Levine and Edwards 1985) includes subtype IIA, a hyperflexion injury with mainly angular displacement due to PLL rupture.

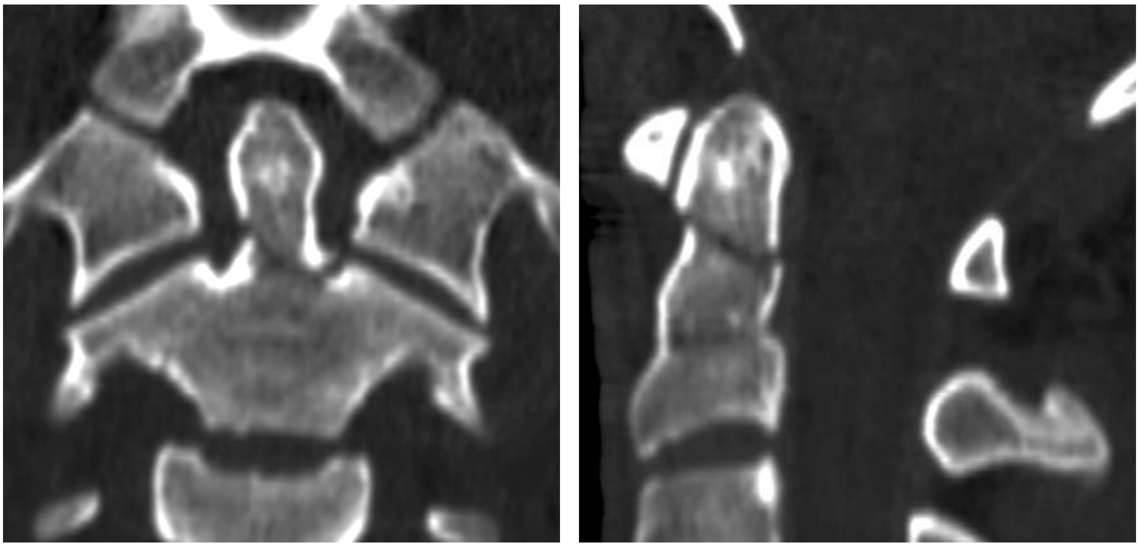

Figure 8. Odontoid process type II fracture.

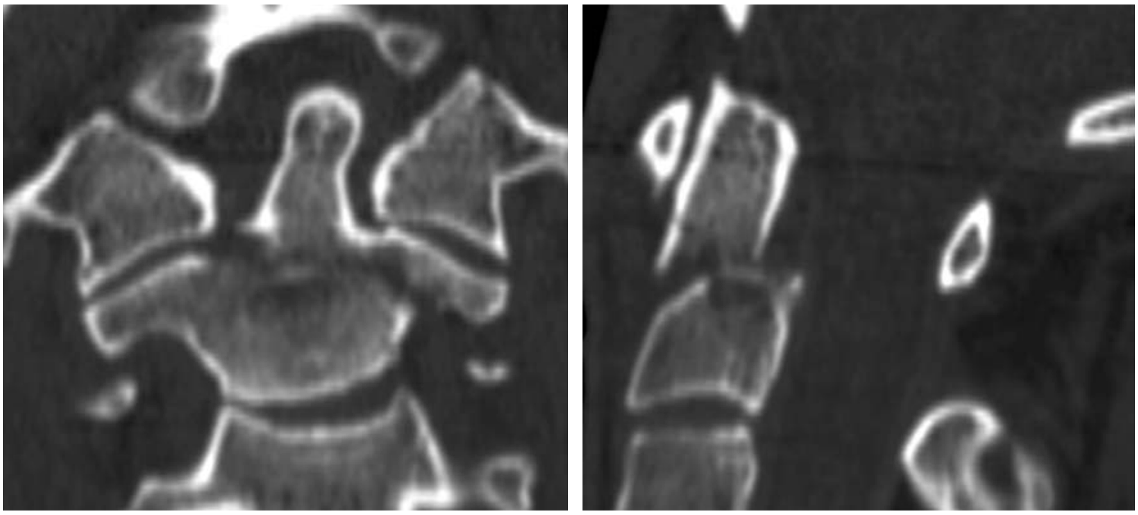

Figure 9. Odontoid process type III fracture.

Figure 10. Type I hangman's fracture.

Lower cervical spine and cervicothoracic junction (C3–Th1)

Fractures of C3 and C4 are uncommon, accounting for 4.2% and 7.0% of cervical spine fractures. Fractures occur more commonly in C5 (15.0%), C6 (20.2%), and C7 (19.1%) and similarly, dislocations and subluxations occur most often in C4/5, C5/6, and C6/7 interspaces (16.4, 25.1, and 23.4% of displacements) and only rarely (3.9% of displacements) in the C7/Th1 interspace (Goldberg et al. 2001). The distribution of fractures, by anatomical structure, is summarized in Table 1.

Table 1. Anatomic location of lower cervical spine fractures (figures from the National Emergency X-radiography Utilization Study, Goldberg et al. 2001).

Vertebral body	29.9%
Pedicle	5.9%
Lateral mass / articular process	14.9%
Lamina	16.4%
Transverse process	9.2%
Spinous process	20.8%
Other	2.9%

Isolated injuries that do not generally need any treatment, and which are easily depicted by modern imaging (Daffner 2004), are isolated spinous and transverse process fractures, wedge compression fractures (with less than 25% compression), avulsion fractures without ligamentous injury, end plate fractures, osteophyte fractures, and trabecular fractures (Goldberg et al. 2001).

Spinal cord injury without radiographic abnormality (SCIWORA) is a very uncommon injury accounting for 0.07 to 0.08% of trauma admissions and 3.3 to 3.8% of all CSI (Hendey et al. 2002, Demetriades et al. 2000). Although initial case series of SCIWORA are reported in children (Pang and Wilberger 1982), the injury predominantly occurs in adults (Hendey et al. 2002). Patients with spinal stenosis and intervertebral disk disease are most susceptible to this injury, and one-third of the patients have central cord syndrome: an incomplete SCI with motor impairment predominantly affecting the upper extremities, sensory loss below the injured level, and bladder dysfunction (Hendey et al. 2002).

Hyperflexion injuries comprise of a relatively heterogeneous group of CSI, in which the injury pattern is modified not only by the magnitude of the force, but also by co-existing additional force vectors. Hyperflexion causes compression of the anterior column structures and distraction of posterior column structures, causing posteriorly both ligamentous injuries and fractures of the spinous processes and laminae. Addition of more force or a distractive force vector increases ligamentous injury, starting posteriorly, sufficient to allow dislocation or fracture (Figure 11) of the facet joints; this may also be unilateral, when the flexion is oblique or with a rotational force vector added. The instability criteria of White et al. (1975) are designed for evaluation of biomechanical stability in such injuries. Unilateral locked facet dislocation without a fracture can be biomechanically stable, but such injuries can be considered clinically unstable, because the anatomical conditions may cause nerve root compression and injury (Vaccaro et al. 2001). After reduction of the dislocation, the motion segment also becomes biomechanically unstable (Crawford et al. 2002). Injuries of the intervertebral disk are common in both uni- and bilateral facet dislocations. Bilateral facet dislocations are associated with extensive ligamentous disruption, frequently involving both ALL and PLL, while in unilateral dislocations, ALL and PLL often remain intact (Vaccaro et al. 2001).

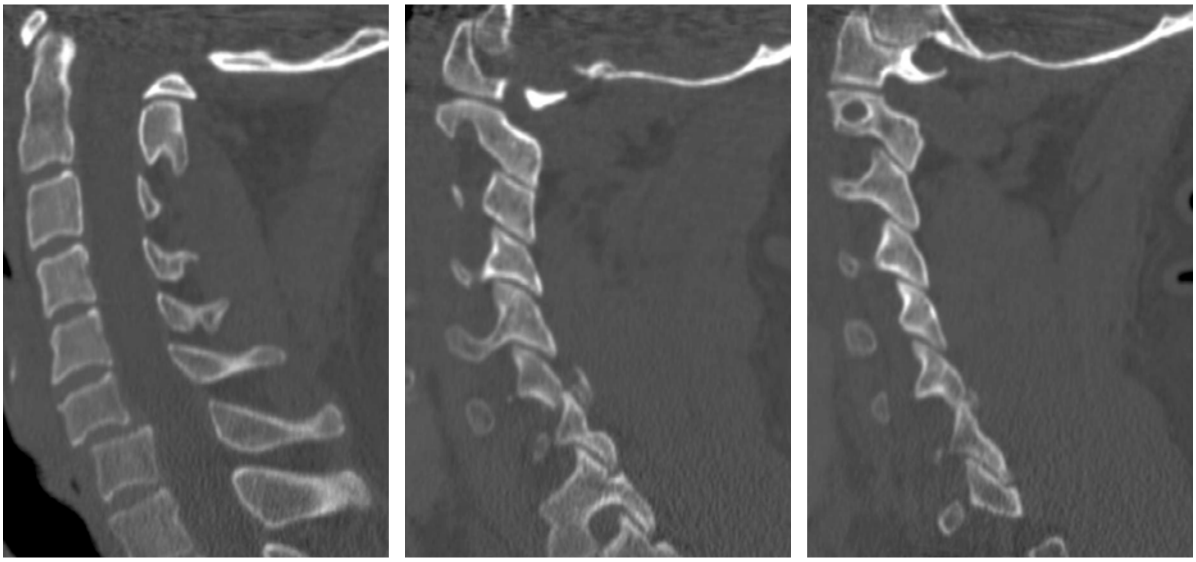

Figure 11. Bilateral fracture dislocation with C6/7 interspinous widening indicating ligamentous injury, and bilateral fractures of C6 inferior articular processes allowing anterior displacement.

Compression and compression-flexion cause compression of the anterior and middle column structures and, with increasing flexion, distraction of the posterior column structures. A wedge fracture of the vertebral body, usually biomechanically stable, is the least severe of the compression-flexion injuries. More forceful compression causes a burst fracture (Figure 12), which frequently involves not only anterior and middle column structures, but also the posterior column. Addition of more flexion to the compression creates a flexion teardrop fracture—a compressive fracture of the vertebral body with a typical triangular fragment from the anterior-lower corner (Figure 13). This injury also includes shearing across the intervertebral disk, retrolisthesis, and frequently a distractive posterior column injury that is seen as fractures or ligamentous ruptures (Kim et al. 1989, Fisher et al. 2002).

Hyperextension causes extension teardrop fracture, ALL rupture or traumatic retrolisthesis. These injuries begin as ligamentous ruptures of the anterior column and extend—with increasing hyperextension—posteriorly as intervertebral disk rupture and in severe cases as PLL, ligamentum flavum, or facet joint ruptures. In these injuries, spinal canal stenosis, as a congenital anomaly or as a result of spondylosis, predisposes to SCI. The radiographic changes are often misleadingly subtle, such as a widened disk space; radiographically, the extent of the ligamentous injury is underestimated (Jónsson et al. 1991a). Great care should be taken not to confuse extension teardrop fractures (Figure 14) with the formerly described flexion teardrop fracture, because extension teardrop—an ALL avulsion of the anterior-inferior vertebral body corner—is significantly more stable.

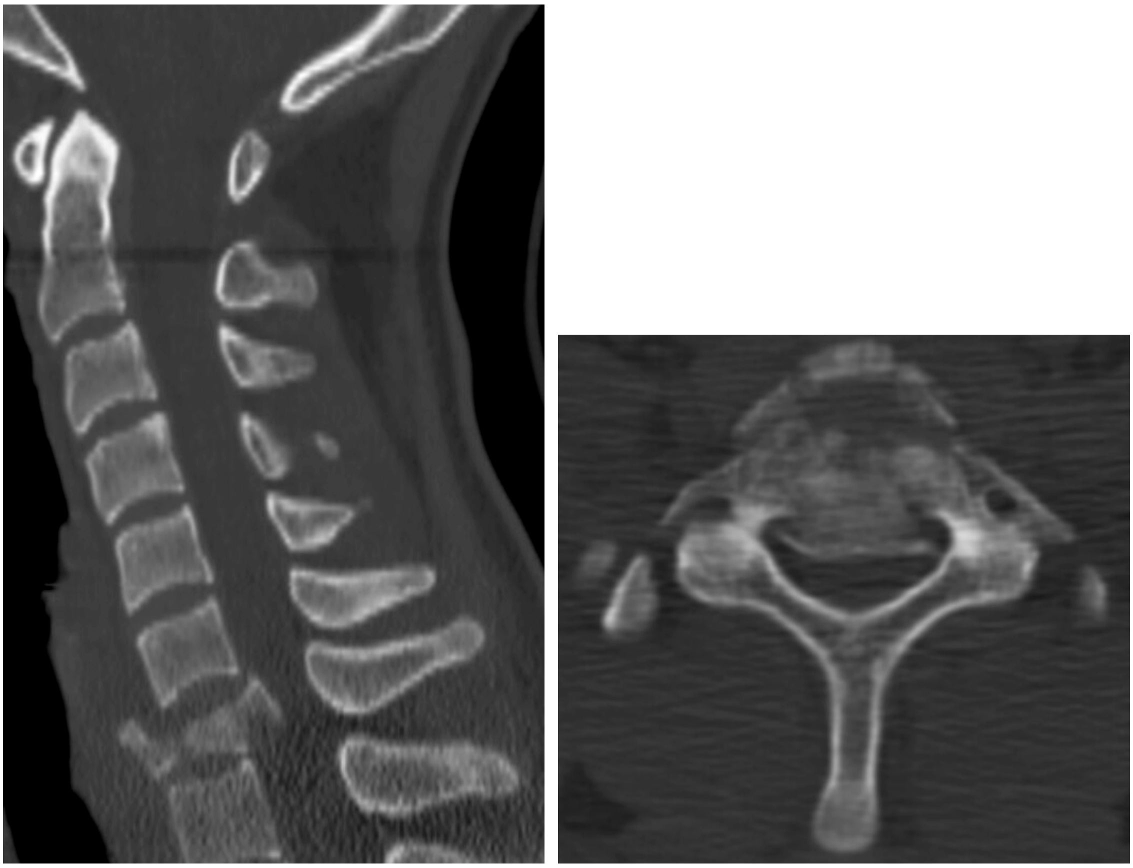

Figure 12. Burst fracture of C7 with a retropulsed vertebral body fragment.

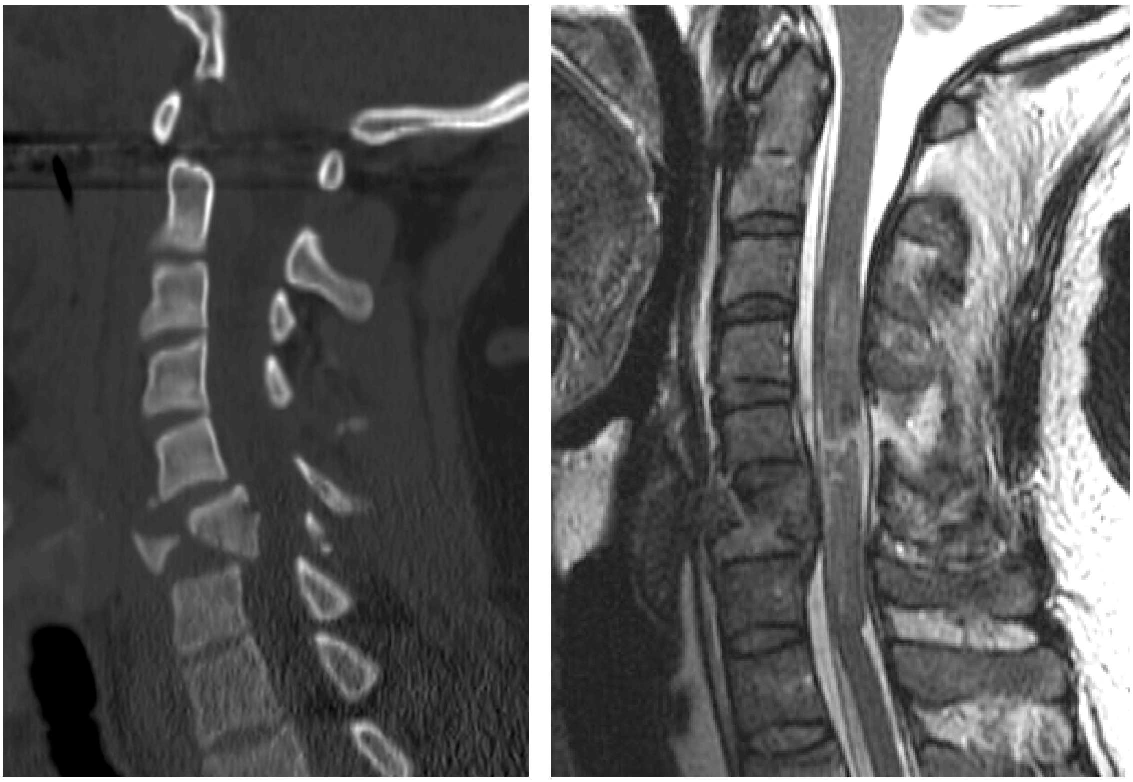

Figure 13. Flexion teardrop fracture with typical triangular fragment anteriorly and ruptures of the intervertebral disk and posterior ligaments, complicated by spinal cord transsection.

Figure 14. Extension teardrop fracture.

CSI in ankylosing spondylitis

Ankylosing spondylitis (AS), also known as Bechterew's disease, is a rheumatic disease with 1.4% incidence and male predominance (Calin and Fries 1975). The chronic inflammatory process primarily affects the ligamentous structures of the spine and sacroiliac joints. Radiologically, the disease appears as enthesopathic inflammatory changes and in advanced disease these ligaments ossify, resulting in an ankylosed vertebral column. In advanced stages of the disease, severe osteoporosis and kyphotic posture of the cervical spine are common. Osteoporosis may occasionally develop before ankylosis (Mitra et al. 2000). Osteoporosis, altered biomechanics with the long lever arms present in the rigid spine, and the kyphotic posture contribute to a high susceptibility to CSI. Spinal fractures are 3.5-fold more common in AS patients than in the general population (Detwiler et al. 1990, Rowed 1992). In AS, 75% of spinal fractures are located in the cervical spine (Hunter and Dubo 1978). In AS patients, CSI can result from minor trauma, most commonly from a simple fall (Graham and Van Peteghem 1989, Rowed 1992). Despite the low-energy nature of these injuries, they are associated with a very high incidence of SCI and of mortality (Weinstein et al. 1982, Foo et al. 1985, Graham and Van Peteghem 1989, Detwiler et al. 1990, Rowed 1992).

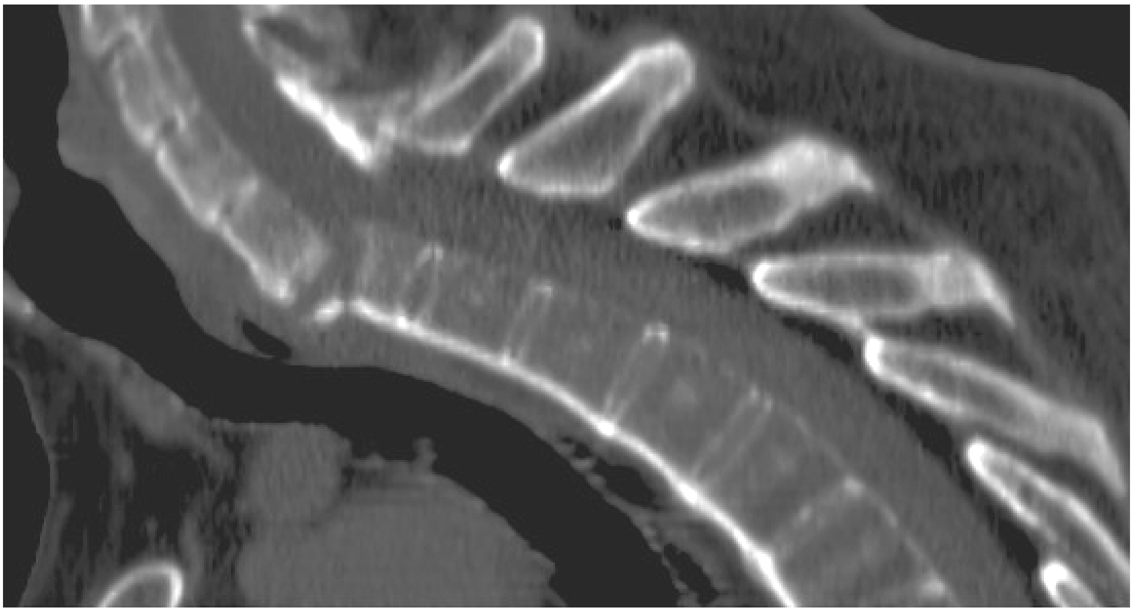

Figure 15. Ankylosing spondylitis complicated by a C6/7 transverse fracture.

Epidemiology of CSI and SCI

In a cross-sectional study Hu et al. (1996) found the annual incidence of spinal fractures in Manitoba, Canada to be 640 per million, 290 per million requiring hospitalization. CSIs account for 33% of the fractures (Hu et al. 1996) and 49–55% (Burke et al. 2001, Sekhon and Fehlings 2001) of SCI. While accidental falls account for the greatest number of CSI, with motor vehicle accidents (MVA) second in occurrence, in spinal injuries requiring hospitalization, MVA is the most common injury mechanism (Hu et al. 1996). Despite their being relatively rare injuries, CSI has economic and social impacts that are extensive (Gunby 1981), because the typical SCI patient is a young adult, and the neurological deficits often persist over a lifetime. The National Emergency X-radiography Utilization Study (NEXUS), searching for clinical decision rules for cervical spine clearance (Hoffman et al. 1998, Goldberg et al. 2001, Lowery et al. 2001, Viccellio et al. 2001, Hendey et al. 2002, Touger et al. 2002), also provided valuable data on CSI epidemiology in blunt trauma. Of 34 069 patients with blunt trauma and suspected CSI, 818 (2.4%) were diagnosed with CSI. The majority of CSI cases occur in those aged 20 to 50 (Figure 16). Reported age distribution (Figure 17) of CSI incidence per admission showed three distinct segments: a relatively low incidence (< 1%) in children, a plateau of 2.2% incidence in adults aged 18 to 64, and a higher 4.6% incidence per admission in those aged 65 years or more. Those over 65 have relatively more injuries of the C1 and C2 segments, especially the odontoid process (Goldberg et al. 2001, Touger et al. 2002), typically sustained in a simple fall from standing height (Lomoschitz et al. 2002).Certain trauma mechanisms and clinical findings indicate a higher risk for CSI. By following such criteria, Hanson et al. (2000b) were able to identify those with an elevated risk and a 13.5% incidence of CSI. Their criteria—the presence any one of which places the patient in the high-risk category—were as follows: High-speed (∅35 mph combined impact) MVA, crash with death at the MVA scene, fall from height (∅10 ft), significant closed head injury or intracranial hemorrhage on computed tomography, neurological symptoms or signs referred to the cervical spine, or pelvic (or multiple extremity) fractures. Converted to ISO units, 35 mph is 56 km/h, and 10 ft is 3 meters.

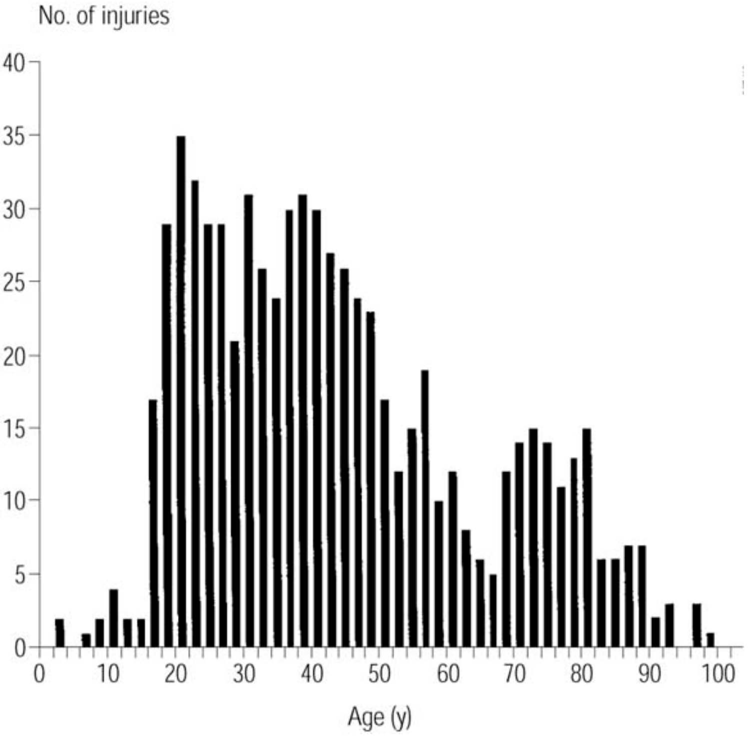

Figure 16. Number of CSI in each age group enrolled in the NEXUS study. Reprinted from Annals of Emergency Medicine, Volume 38, Lowery DW, Wald MM, Browne BJ, Tigges S, Hoffman JR, Mower WR, NEXUS Group, Epidemiology of cervical spine injury victims, Pages 12–16, Copyright (2001), with permission from American College of Emergency Physicians.

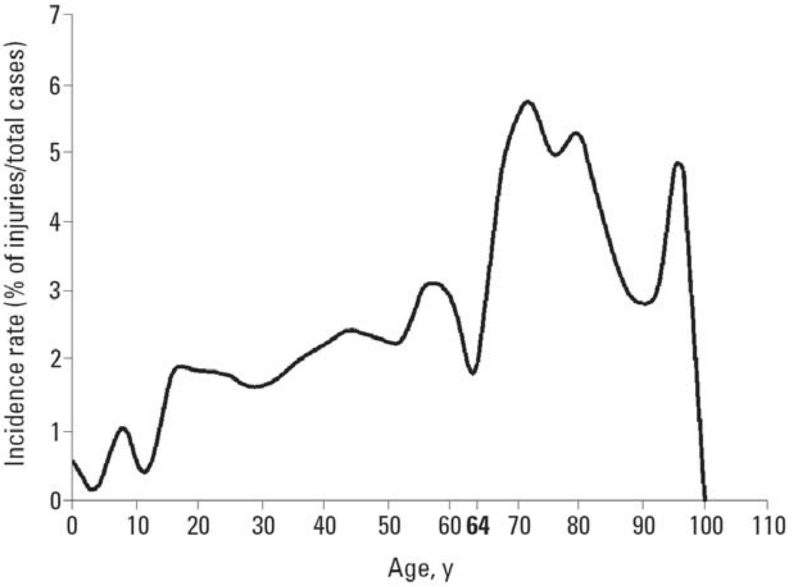

Figure 17. Incidence of CSI in different age groups according to the NEXUS study. Reprinted from Annals of Emergency Medicine, Vol 40, Touger M, Gennis P, Nathanson N, Lowery DW, Pollack CV, Hoffman JR, Mower WR, Validity of a decision rule to reduce cervical spine radiography in elderly patients with blunt trauma, Pages 287–293, Copyright (2002), with permission from the American College of Emergency Physicians.

The annual incidence of SCI is 5 to 40 per million, 49 to 55% of which result from CSI (Burke et al. 2001, Sekhon and Fehlings 2001). The median age of SCI patients is 31.6 years with a 3:1 male predominance and 59.5% are unmarried (Burke et al. 2001). The annual incidence of SCI is considerably higher (78.3 per million) in the age group 18 to 24 than among those of 25 to 44 (25.4 per million). Whereas pre-hospital mortality in SCI is high, 48 to 79% (Kraus et al. 1975), the survival rate after hospitalization is generally good, 83 to 95% (Kraus 1980, Burke et al. 2001). Mortality rates before and after hospitalization over the past 20 years have declined (Sekhon and Fehlings 2001). Non-survivors are more likely to have an injury of the cervical spine and have less often used safety precautions such as a seatbelt or a helmet; up to half (47%) of the SCI patients are under the influence of alcohol at the time of the accident. MVAs account for more than half of SCIs (Burke et al. 2001). Of SCI patients, 20 to 57% have significant associated injuries to other organ systems (Sekhon and Fehlings 2001), most commonly the head injuries seen in 39% of CSIs (Burke et al. 2001). The severity of head injury correlates with incidence of CSI: 1.4% in patients with Glasgow Coma Scale (GCS) score 13 to 15, 6.8% in GCS 9 to 12, and 10.2% in GCS Ω8 (Demetriades et al. 2000).

Diagnosis of CSI

Clinical cervical spine clearance

The clinical decision rules studied (Hoffman et al. 1998) and validated (Hoffman et al. 2000) by the NEXUS group are highly accurate for the task for which they were designed: In some patients they can rule out virtually any unstable CSI. The NEXUS criteria for clinical exclusion of CSI are the following: no evidence of intoxication, no posterior midline neck tenderness, no painful distracting injuries, normal level of alertness, and no focal neurologic deficit. Patients who meet all five criteria have a very low risk for CSI (99.8% negative predictive value). The sensitivity of the decision rule is high (99.0%), but due to its low specificity (12.9%), its positive predictive value is low (2.7%). Use of the NEXUS criteria could, in theory, reduce the number of radiographic examinations of the cervical spine by approximately 20% (Hoffman et al. 2000).

Radiography

Despite advances in computed tomography (CT) and MRI technology, plain radiography is still the fundamental primary imaging method for CSI. In plain radiographic clearance of the cervical spine, three views including lateral, anteroposterior, and open-mouth odontoid are the minimum requirement (Vandemark et al. 1990). Utilization of supine oblique views in addition to these three views does not significantly improve detection of CSI (Freemyer et al. 1989, Basak et al. 2001); it may, however, improve diagnostic confidence (Turetsky et al. 1993) and more specifically the confidence of excluding fractures (Basak et al. 2001). The use of five views may be cost-efficient by reducing the need for CT after non-visualization of the cervicothoracic junction (Kaneriya et al. 1998). Supplementary CT is cost-effective in radiographic non-visualization of the cervicothoracic junction (Tan et al. 1999). While radiography is only 83 to 93% sensitive in detecting cervical spine fractures (Gerrelts et al. 1991, Turetsky et al. 1993, West et al. 1997), it is 92 to 96% sensitive and 85 to 98% specific in detection of clinically relevant fractures (Blackmore et al. 1999). Interestingly, in the

NEXUS study radiography missed only 0.4% of clinically relevant CSI (Mower et al. 2001), which may be a result of verification bias. The use of supplementary flexion-extension lateral view radiographs is controversial (Geck et al. 2001, Daffner 2004).

The risk of neurological deterioration in undetected CSI is approximately 29% (Davis et al. 1993). The most common cause of false-negative cervical spine radiography is the inadequate series of roentgenograms (Gerrelts et al. 1991, Davis et al. 1993) that are more common in high-risk patients (Blackmore and Deyo 1997). In trauma patients radiographic screening is thus insensitive (Lee et al. 2001). D'Alise et al. (1999) reported, concerning high-risk patients with normal radiography and for whom reliable clinical examination could not be performed, a 26% incidence of osseous or ligamentous injury in MRI. Similarly, Schenarts reported in trauma patients a 45% false-negative rate in radiographic detection of C0–3 injuries, using, as gold standard, CT (Schenarts et al. 2001).

Computed tomography and multi-detector computed tomography

Helical CT is an accurate and reliable imaging modality widely used in modern emergency radiology (Novelline et al. 1999). In cervical spine trauma, CT is both cost- and time-effective, and has been recommended for screening in high-risk patients (Blackmore et al. 1999, Hanson et al. 2000a, Daffner 2001). Clinical decision rules can help to identify those blunt trauma patients at higher risk for CSI (Hanson et al. 2000a, Daffner 2004). Helical CT can detect CSI at a 95 to 98% sensitivity (Nunez et al. 1994, Hanson et al. 2000b, Holmes et al. 2002) and 93 to 100% specificity (Hanson et al. 2000b, Ptak et al. 2001). Whereas detection of mild vertebral body compression fractures and mild subluxations are known pitfalls (Holmes et al. 2002), odontoid fractures are reliably detected (Weisskopf et al. 2001, Holmes et al. 2002). 3D surface reconstruction images do not generally enhance diagnostic accuracy, but may be of value in interpretation of rotational CSI (Kösling et al. 1997). CT is unreliable in assessment of ligamentous injuries and SCI (Holmes et al. 2002). Compared to conventional CT, multi-detector CT (MDCT) is faster, and has fewer motion artifacts, partial volume effects, and image noise; it also allows isotropic voxel dimensions and high quality multiplanar reformation (MPR) images (Rydberg et al. 2000, Li and Fishman 2003).

Skin dosimetry of 3-mm single-slice cervical spine scan shows an approximate 14-fold increase in radiation dose compared to conventional three-view radiography (Rybicki et al. 2002). Up till now, no similar comparisons of radiation doses in cervical spine MDCT have appeared. The radiation dose in thoracic and abdominal MDCT can be 2.6-fold that of single-slice techniques (Giacomuzzi et al. 2001) but may be reduced by 40% by beam-tracking methods (Toth et al. 2000).

MRI

MRI has the ability to visualize soft-tissue injuries and may serve as a complement to radiography and CT. It can aid in assessment of transverse ligament injuries in Jefferson's fractures (Dickman et al. 1996), of intervertebral disk and PLL integrity in type II and III hangman's fractures, ALL and intervertebral disk integrity in hyperextension injuries (Davis et al. 1991), posterior ligaments and facet joints in hyperflexion injuries (Kerslake et al. 1991, Leite et al. 1997), and also of post-traumatic disk herniation and hematoma (Rizzolo et al. 1991, Vaccaro et al. 2001), brachial plexus (Aagaard et al. 1998), and SCI (Flanders et al. 1990). In addition to conventional T1 (longitudinal relaxation) and T2 (transverse relaxation) -weighted sagittal and axial sequences, sagittal short time to inversion recovery (STIR) sequences are invaluable in evaluation of spinal trauma (Kerslake et al. 1991). Future development of kinematic MRI (Karhu et al. 1999) may contribute to detection of ligamentous instability. Detection of cervical spine fractures on MRI is highly dependent on interpreter experience. While most fractures can be shown by MRI (Katzberg et al. 1999), in a true clinical setting it reveals only 55% of fractures: known pitfalls include Jefferson's fracture, fractures of pedicles, lateral masses including facet joints, or laminar and spinous processes (Holmes et al. 2002). The presence of ligamentous abnormalities or hematoma—which are readily depicted by STIR sequences—may, however, draw attention to fractures indirectly.

Cervical spine clearance in ankylosing spondylitis

Due to osteoporosis, anatomic distortion, or rigidity, fractures in AS are difficult to diagnose by plain radiography (Broom and Raycroft 1988, Finkelstein et al. 1999). Delayed diagnosis, however, places the patient at high risk for late neurological complications (Broom and Raycroft 1988), because without appropriate treatment the fractures tend to develop into unstable pseudoarthrosis (Cawley et al. 1972). Accurate and sensitive diagnostic primary imaging is thus essential. In AS, conventional CT is capable of yielding valuable information on fracture delineation and spinal canal compromise (Goldberg et al. 1993, Wu and Lee 1998, Taggard and Traynelis 2000). As in other CSIs, MRI can show the fractures—ones both acute and ones with pseudoarthrosis—and also help evaluate severity of the SCI in AS patients (Goldberg et al. 1993, Pedrosa et al. 2002).

Treatment options and clinical results in CSI

Occipitocervical junction and upper cervical spine

In neurologically uncomplicated fractures of the occipital condyles, external stabilization using a stiff collar is sufficient (Capuano et al. 2004). Because untreated and conservatively treated atlanto-occipital dislocations are often complicated by neurological deterioration, surgical internal stabilization is recommended (Traynelis et al. 1986, Hadley et al. 2002c). Isolated fractures of the anterior or the posterior arch of the atlas and combined anterior and posterior arch fractures with an intact transverse ligament (type I injuries) have been successfully treated with rigid collars, sterno-occipitomandibular immobilizing devices, and HTV. No study has provided evidence for using one of these devices over the other (Hadley et al. 2002d). For combined anterior and posterior arch fractures with evidence of transverse ligament rupture (including type II Jefferson's fractures), HTV and surgical stabilization are the main treatment options, yet no evidence exists as to their performance relative to each other (Hadley et al. 2002d).

Type I odontoid fractures are usually stable and clinically non-problematic avulsion fractures of the odontoid process tip (Anderson and D'Alonzo 1974), while only limited knowledge of such injuries yet exists (Julien et al. 2000).

Type II odontoid fractures are unstable, often failing to unite by conservative treatment (Julien et al. 2000). The optimal treatment—external stabilization or surgery—and indications for early surgery are controversial (Hadley et al. 2002e). Main treatment options include HTV for all type II fractures (Lind et al. 1987), for non-displaced fractures only (Dunn and Seljeskog 1986, Hanssen and Cabanela 1987), and primary surgical treatment (Southwick 1980, Maiman and Larson 1982, Aebi et al. 1989). Treatment by cervical brace alone provides insufficient stability and produces lower osseous union rates than does HTV (Polin et al. 1996). While HTV provides an immobilization superior to that of a soft collar, a Miami J collar, or a Minerva brace (Richter et al. 2001), it cannot completely immobilize the cervical spine; it allows some movement, especially in the upper cervical spine (Lind et al. 1988a). A substantial variation also occurs between subjects and between HTVs from different manufacturers (Fukui et al. 2002). Surgical treatment, meaning either posterior fusion with bone grafting and wires (Brooks and Jenkins 1978), multistrand cables (Figure 18), posterior atlanto-axial screw fixation (Grob and Magerl 1987), or anterior screw fixation (Figure 19), is effective but technically demanding and is associated with complications (Aebi et al. 1989, Andersson et al. 2000). It is well accepted that surgical treatment is preferable for patients for whom conservative treatment cannot be undertaken or conservative treatment has failed. Despite only a few cases of type IIA (Hadley et al. 1988) comminuted odontoid base fractures described in literature, they are considered to be highly unstable (Hadley et al. 1989, Koc et al. 2001), difficult to reposition and requiring early surgical treatment.

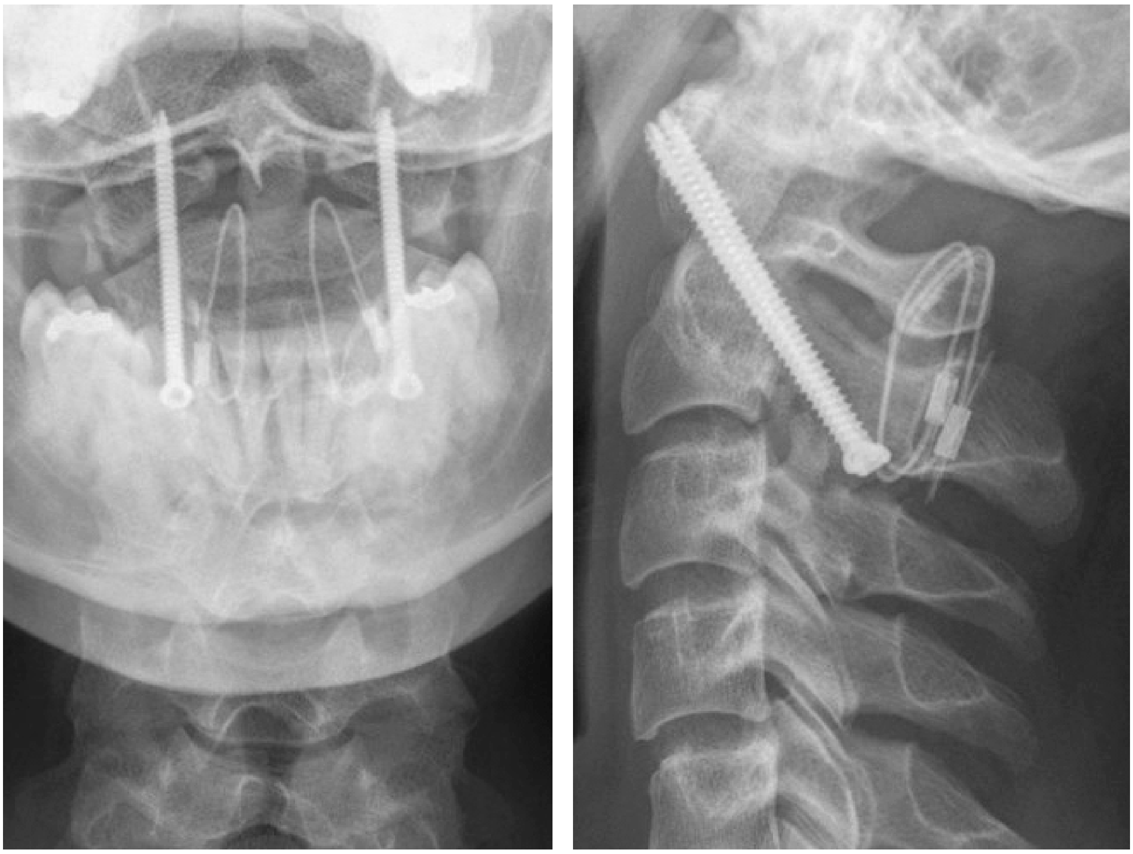

Figure 18. Atlanto-axial posterior fusion using multistrand cables and transarticular screws.

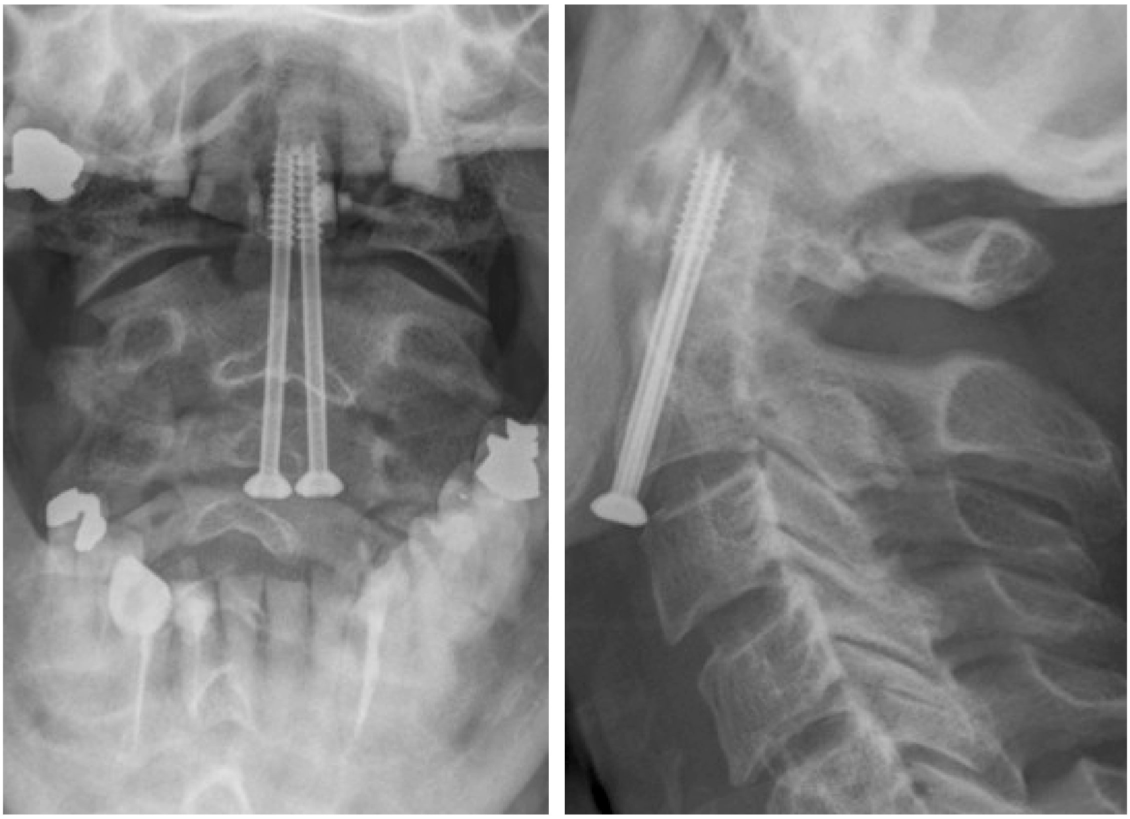

Figure 19. Anterior fixation of the odontoid process with screws.

In type III fractures, surgical treatment is generally unnecessary, as most heal well by conservative treatment such as HTV or Minerva cast (Anderson and D'Alonzo 1974, Hadley et al. 1989, Polin et al. 1996, Hadley et al. 2002e). A cervical collar may, however, provide insufficient immobilization for some type III fractures (Clark and White 1985).

Most hangman's fractures, being most commonly type I, heal by conservative treatment with a rigid cervical collar or a HTV. Surgical stabilization, either posterior or anterior, is an option in cases with severe dislocation or angulation, i.e., type II, IIA, and III injuries (Hadley et al. 2002e).

Lower cervical spine and cervicothoracic junction

A relatively safe and efficient way of reducing cervical spine displacements in awake patients is skull traction with progressively increasing weights—without general anesthesia (Star et al. 1990, Hadley et al. 2002a). The repositioning of fractures and dislocations by skull traction relies on the tensile force applied to PLL to re-align the posterior vertebral body margins (Harrington et al. 1993). HTV has been successfully used, in addition to unstable upper cervical spine injuries, in both compressive flexion and distractive flexion injuries of the lower cervical spine (Lind et al. 1988b). Late symptoms, however, such as mild or moderate neck discomfort and reduced ROM may persist for years after such treatment (Lind et al. 1988b).

Rorabeck et al. concluded that patients with unilateral facet dislocations should be initially treated with initial halo traction in an attempt to obtain reduction (Rorabeck et al. 1987). They also recommended HTV in neurologically intact patients in whom closed reduction was successful. In contrast, Hadley et al. (1992) concluded that facet dislocations without apparent fracture do not respond well to conservative treatment.

Surgical treatment of cervical spine dislocations allows earlier mobilization of the patient and shortens the primary hospital stay (Cotler et al. 1990). In posterior internal stabilization (Omeis et al. 2004), numerous fixation methods have been used successfully: interspinous or interlaminar fixation such as Rogers interspinous wiring (Rogers 1942), Bohlmann’s modification of the Rogers wiring with addition of bone grafting and triple-wires (Bohlmann 1979), the interspinous Daab plate (Böstman et al. 1984), and interspinous or sublaminar wiring with multistrand cables (Huhn et al. 1991). Other methods are direct fixation of lateral masses with plates and screws (Roy-Camille et al. 1992) and various instrumentation utilizing rods and screws (Richter et al. 2000, Deen et al. 2003). Triple-wire fixation and direct fixation of lateral masses with plates are biomechanically equally stable (Mihara et al. 2001), but lateral mass fixation with screws and rods may be even more efficient in preventing pseudoarthrosis (Deen et al. 2003). Posterior fixation can stabilize one- and two-column posterior injuries, but without additional anterior stabilization these are insufficient for three-column injuries (Kreshak et al. 2002).

The era of anterior instrumentation began when Bohler (1967) reported the use of anterior plate fixation in cervical spine fractures. Further evolution of anterior instrumentation included the AO cloverleaf or H-plate (Orozco and Llovet 1970) and the Caspar plate requiring bicortical screw positioning (Caspar et al. 1989). As use of hollow screws locking to the anterior plate eliminates the requirement for posterior cortex purchase (Kostuik et al. 1993), a variety of anterior instrumentation sets followed (Moftakhar and Trost 2004). Screw loosening in such instrumentation occurs in approximately 5% of cases (Kostuik et al. 1993). Anterior plates can stabilize not only compressive flexion and extension injuries, but also distractive flexion injuries (dislocations and fracture dislocations), by either non-locking (Caspar et al. 1989) or locking cervical spine plates (Jónsson et al. 1991b). Although stabilization of distractive flexion injuries by anterior non-locking plates does not biomechanically provide a completely rigid construct (Sutterlin et al. 1988), in vivo they have been successful (Garvey et al. 1992).

Locking plates provide, in biomechanical testing, a more rigid construction than the unconstrained Caspar plate (Grubb et al. 1998). As complete removal of mechanical axial loading from the healing bone results in negative bone remodeling and net bone loss (Rubin and Lanyon 1984), concerns have arisen about locking plates being too rigid. Dynamic plates, allowing minimal axial load to the anterior bone graft, are under experimental and clinical evaluation (Moftakhar and Trost 2004), yet biomechanical testing has revealed only minor differences between axial loading capabilities of locking and dynamic plates (Brodge et al. 2001). After anterior interbody fusion, 92% of cases develop degeneration of adjacent interspaces, due to altered biomechanics or natural progression of pre-existing degenerative disk disease, or both (Goffin et al. 2004).

For CSI in AS, the optimal treatment—conservative or surgical fusion—is controversial (Apple and Anson 1995). Anterior, posterior, or a combination of both anterior and posterior (Detwiler et al. 1990, Rowed 1992, Fox et al. 1993, Olerud et al. 1996, El Masry et al. 2004) internal stabilization methods has been successful. Both conservative and surgical treatments are associated with high complication rates.

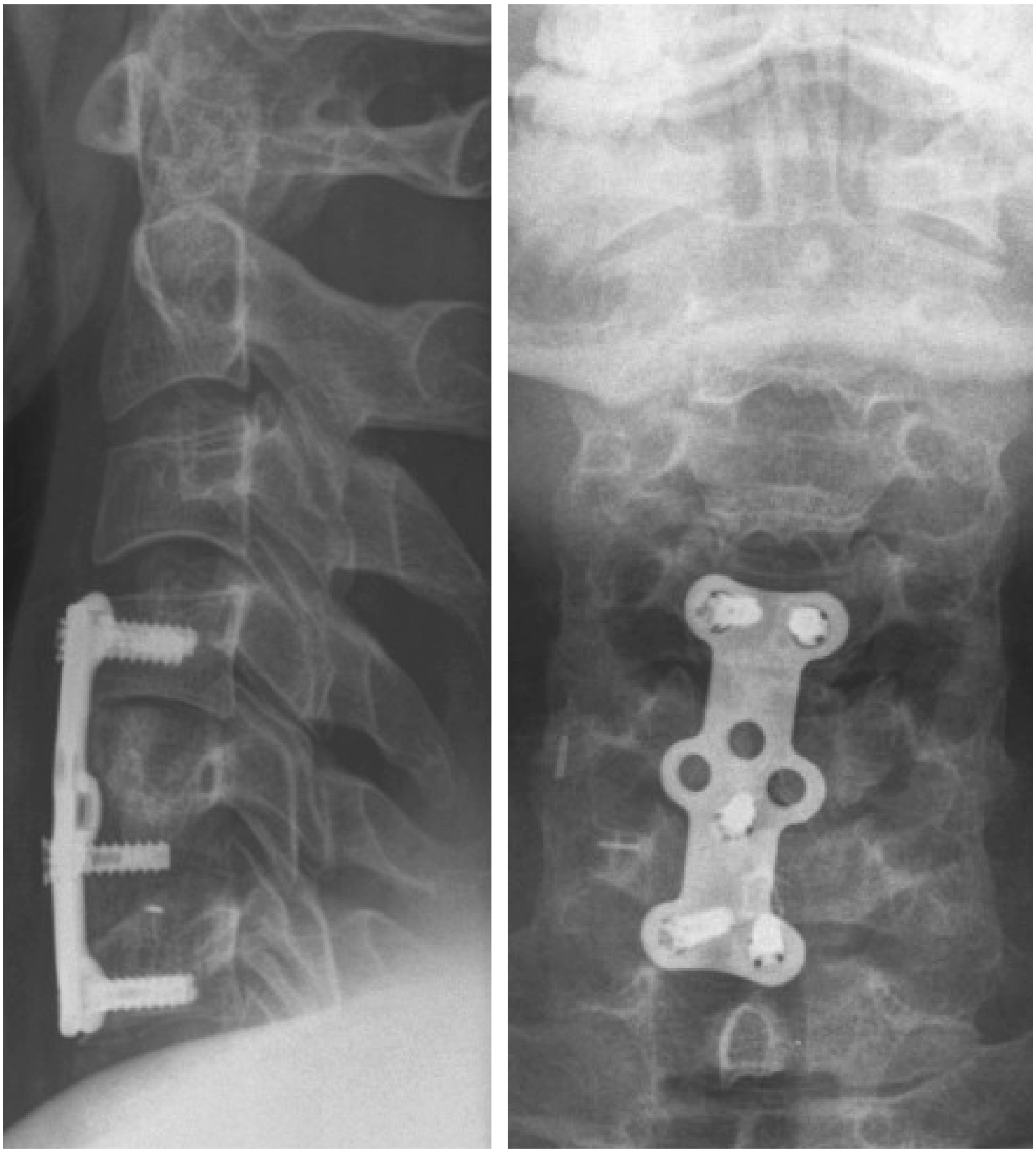

Figure 20. Anterior decompression and stabilization with a locking plate.

AIMS OF THE STUDY

I Burst and flexion teardrop fractures

To compare the results of conservative and anterior surgical treatment of cervical burst and flexion teardrop fractures.

II Fracture dislocations

To compare results of conservative treatment of subaxial fracture dislocations and posterior fusion with bone grafts and interspinous wiring.

III Non-union in odontoid process type II fractures

To determine risk factors associated with failure of HTV treatment in type II odontoid fractures.

IV MDCT of odontoid process type IIA fractures

To assess the occurrence of the comminuted type IIA subtype in type II odontoid fractures.

V Fractures in ankylosing spondylitis

To assess MDCT findings in patients with advanced AS plus suspected CSI and to compare MDCT findings with radiography and MRI.

MATERIALS AND METHODS

Patients

Burst and flexion teardrop fractures (I) and fracture dislocations (II)

The databases of Töölö hospital, Helsinki were queried by means of the International Statistical Classification of Diseases and Related Health Problems (ICD-10 and the earlier versions ICD-9 and ICD-8) for subaxial cervical spine fractures, fracture dislocations, and dislocations. Files and radiographs of patients with cervical burst and flexion teardrop fractures (I) and fracture dislocations (II) were reviewed. Patients with known malignancy or AS were excluded.

Study I included patients treated between 1980 and 1995 for burst (compression or compression-flexion fracture of both anterior and middle, and also frequently the posterior column) or flexion teardrop (compression-flexion fracture of the vertebral body with triangular anterior fragment, extensive disruption of ligaments, and retrolisthesis) fractures, fulfilling inclusion criteria as follows: age at least 15 years; minimum 6-month follow-up; and either conservative treatment with skull traction or HTV or alternatively anterior surgical decompression, followed by bone grafting and Caspar plate fixation (Caspar et al. 1989). A total of 69 patients met the inclusion criteria for Study I and were divided into two groups according to the primary treatment method—conservative or primary surgical.

Study II included patients treated between 1977 and 1998 for subaxial fracture dislocations (hyperflexion or hyperflexion-rotation injury with osseous and ligamentous posterior column disruption), fulfilling inclusion criteria as follows: acute posterior column injury meeting the instability criteria of White (White et al. 1975); treatment by either conservative means or by posterior bone grafting and interspinous wiring (Bohlman 1979); a minimum 3-month follow-up for those without SCI and 6 months for those who had sustained SCI. The instability criteria, the presence of any of which indicates instability (White et al. 1975) were "all the anterior or all the posterior elements are destroyed or unable to function", "more than 3.5 mm horizontal displacement of one vertebra in relation to an adjacent vertebra measured on lateral roentgenograms (resting or flexion-extension)", and "more than 11 degrees of rotation difference to that of either adjacent vertebra measured on a resting lateral or flexion-extension roentgenogram." A total of 106 patients met the inclusion criteria for Study II and were divided into two groups based on mode of treatment: conservative or primary surgical.

Non-union in odontoid process type II fractures (III) and MDCT of type IIA fractures (IV)

For Study III, patients treated by HTV for acute fractures of the odontoid base (type II fractures) in Töölö Hospital from 1982 to 2002 were identified by polls of hospital records based on ICD and by review of respective medical records. Patients with malignancy, rheumatoid disease, or other medical conditions potentially affecting the outcome were excluded, as were patients lost to follow-up or patients subjected to primary surgical fusion or having been treated primarily by orthosis other than HTV. A total of 69 patients fulfilling the inclusion criteria were included in Study III. A different approach was chosen for Study IV: by the Picture Archiving and Communication System (PACS), all 1428 cervical spine MDCT scans obtained at Töölö hospital between August 2000 and November 2002 were reviewed to find acute odontoid fractures. Only patients with acute odontoid base fractures were included. A total of 26 patients met the inclusion criteria of Study IV.

Fractures in ankylosing spondylitis (V)

Based on PACS, all 2282 cervical spine MDCT scans obtained at Töölö hospital between August 2000 and June 2003 were reviewed. A total of 18 AS patients met the inclusion criteria: suspected CSI, cervical spine ankylosis caused by AS, and initial cervical spine imaging by MDCT. No patients with diffuse idiopathic skeletal hyperostosis, rheumatoid arthritis, or other ankylosing diseases were included.

Methods

Burst and flexion teardrop fractures (I) and fracture dislocations (II)

Radiographs obtained on admission, on discharge, and at the end of follow-up were reviewed and measured. Radiography included routine anterior and lateral views (70 kV, 25 mAs, 1.5m distance), supplemented when necessary by a lateral swimmer's view and oblique views. To exclude the effects of geometric magnification and of differences in patient size, measurements of distances were also correlated with the adjacent superior vertebral body sagittal (VBS) distance and expressed as percentages of it (%VBS). The measurements included spinal canal encroachment by retropulsed fragments (I), vertebral displacement (II), and kyphotic deformity (I, II). Neurological injury was, at respective points of time, assessed from hospital records by Frankel's five-grade SCI classification (Table 2). Symptoms of radiculopathy were also noted.

Table 2. Frankel's classification of neurological functioning (Frankel et al. 1969).

Grade	
A	Complete motor and sensory loss
B	Preserved sensation only
C	Non-functional motor activity
D	Functional motor activity
E	Complete neurological recovery

Non-union in odontoid process type II fractures (III)

The medical records of the 69 patients provided information on accompanying injuries, neurological status, delay of diagnosis or treatment, treatment, and clinical outcomes. Dislocations, angulation, and fracture gaps were measured from radiographs taken on admission and before discharge (i.e., after application of HTV). To assess osseous fracture union, radiographs at the end of follow-up, including lateral projection bending radiographs, were studied.

MDCT of odontoid process type IIA fractures (IV)

All cervical spine scans were performed with a four-slice MDCT scanner (Lightspeed QX/I; G.E. Medical Systems, Milwaukee, WI, USA) with 1.25-mm slice thickness and archived in PACS (IMPAX; Agfa-Gevaert N.V., Mortsel, Belgium) as 2.5-mm axial slices and 1.5-mm sagittal and, whenever considered necessary, coronal reformatted slices. In addition, the original 1.25-mm axial slices were available in 16 cases. MDCT scans were interpreted separately by two emergency radiologists, and the fractures classified as either the common type II or as comminuted (type IIA) in cases of any additional free fragments in the vicinity or within the fracture gap.

Fractures in ankylosing spondylitis (V)

Cervical spine MDCT scans were obtained with a four-slice MDCT scanner (Lightspeed QX/I; G.E. Medical Systems, Milwaukee, WI, USA). A 1.25-mm slice thickness was used, and the scans were archived in PACS (IMPAX; Agfa-Gevaert N.V., Mortsel, Belgium) as 2.5-mm slices. Sagittal MPR from the 1.25-mm slices was done with a 1.5-mm slice thickness and reconstruction increment. Coronal MPR was used when necessary. Any plain radiography available included standard anterior and lateral views, supplemented, when necessary, by a lateral swimmer's view. The MDCT scans and, when available, the plain radiographs of the ankylosed spines were interpreted by two emergency radiologists by consensus. The MRI scans, when available, were reviewed by a third emergency radiologist in a blinded manner. Cervical spine MRI was obtained with either a 1.5T closed-bore scanner (Signa LX 1.5T; G.E. Medical Systems, Milwaukee, WI, USA) or a 0.23T open scanner (Outlook GP; Picker Nordstar, Helsinki, Finland). Routine MRI included sagittal T1- and T2-weighted fast spin echo sequences in addition to a sagittal STIR sequence, completed with, whenever necessary, axial T1- and T2-weighted fast spin echo sequences and a sagittal T2* (transverse relaxation obtained using gradient echo) sequence.

Statistical analysis

The chi-square test and Fisher's exact test served for statistical testing of proportions and the Mann-Whitney rank sum test for continuous non-parametric variables in Studies I, II and III. In addition, binary logistic regression analysis (backward method) was used in Study III and the Kappa test in Study IV. The BMDP New System for Windows 1.1 (Statistical Solutions, Cork, Ireland) and SPSS for Windows 9.0 (SPSS Inc., Chicago, IL, USA) statistical software were used.

RESULTS

Burst and flexion teardrop fractures (I)

The fracture was located in C5, C6 or C7 in 67 (97%) of the cases. Of the 69 patients (Table 3), 34 were treated conservatively: 29 with skull traction (average duration 5 weeks) and 5 with a HTV (average duration 8 weeks). Afterwards, a collar (Camp Philadelphia, Cervical Collar Company, Westville, NJ, USA) was applied for 8 weeks on average. Those surgically treated comprised of 35 patients who underwent primary reduction by skull traction followed by anterior decompression, iliac bone grafting, and anterior fixation by use of the Caspar plate (Aesculape, Tuttlingen, Germany). The surgically treated patients wore a collar for a mean 11 weeks. The average follow-up was 28.9 months (range 6 months–14 years) in the conservative treatment group and 15.9 months (6 months–3 years) in the surgical treatment group.

Table 3. Characteristics of the 69 patients. Modified from Koivikko MP, Myllynen P, Karjalainen M, Vornanen M, Santavirta S, Conservative and operative treatment in cervical burst fractures, Arch Orthop Trauma Surg 2000; 120:448–451, with permission from Springer-Verlag.

	Primary method of treatment	
	Conservative	Surgical
N (male:female)	34 (27:7)	35 (29:6)
Age, years (range)	30.3 (15–64)	32.9 (17–83)
Trauma, N		
Motor vehicle accident	18	16
Diving	8	9
Other	8	10

Complication rates (Table 4) were similar in both groups, occurred mainly during the primary hospital stay, and were related to severity of the SCI rather than to method of treatment. Posterior vertebral body alignment was better restored in the surgical group (Table 5), with kyphotic deformities and residual displacement more common among those conservatively treated. Three of the conservatively treated underwent late surgical stabilization for residual instability, and two surgical patients were re-operated—one for screw loosening and one because of the too long screws used in the primary operation. Neurological recovery was more common in the surgical group: 13 of 23 (Frankel grade A–D SCI) improved one grade or more, in contrast to only 4 of the 18 conservatively treated SCI (p = 0.027, chi-square test, Table 6). Use of methylprednisolone (2 conservatively and 14 surgically treated patients) and extent of posterior cortex displacement upon arrival did not correlate with the neurological outcome. Neurological outcome correlated with proper reduction of the posterior cortex fragments; those who recovered at least one Frankel grade had significantly less displacement at the end of the follow-up than did those who did not recover (7.2 vs 18.3 %VBS, p = 0.0006, Mann-Whitney rank sum test).

Table 4. Complications during the primary hospital stay and during follow-up. Modified from Koivikko MP, Myllynen P, Karjalainen M, Vornanen M, Santavirta S, Conservative and operative treatment in cervical burst fractures, Arch Orthop Trauma Surg 2000; 120:448–451, with permission from Springer-Verlag.

Complication	Primary method of treatment			
	Conservative		Surgical	
	Hospital	Follow-up	Hospital	Follow-up
Cardiac	2	—	4	—
Respiratory	12	1	10	1
Urologic	7	6	8	5
Gastrointestinal	2	—	4	—
Deep venous thrombosis	4	—	—	2
Pulmonary thromboembolism	2	—	—	—
Decubitus ulcers	3	6	5	5
Related to orthosis pins	—	1	—	3
Other	6	—	2	—
Death	3	—	1	—

Table 5. Radiographic data on admission and at end of follow-up.

	Primary method of treatment	
	Conservative	Surgical
Posterior cortex displacement, %VBS		
Admission	24% (SD 13.1)	24% (SD 14.9)
End of follow-up	21.5% (SD 8.3)	7.4% (SD 8.8)
Kyphotic deformity, degrees		
Admission	6.6 (SD 8.5)	8.0 (SD 10.2)
End of follow-up	12.6 (SD 10.0)	-2.2 (SD 13.9)

Table 6. Neurological status assessed by Frankel's grading on admission and at end of follow-up. Modified from Koivikko MP, Myllynen P, Karjalainen M, Vornanen M, Santavirta S, Conservative and operative treatment in cervical burst fractures, Arch Orthop Trauma Surg 2000; 120:448–451, with permission from Springer-Verlag.

On admission	At follow-up									
	Conservative					Surgical				
	A	B	C	D	E	A	B	C	D	E
A	9					8	2	2		
B		4		1			1	1	3	
C				2	1				3	1
D				1					1	1
E					13					11

Fracture dislocations (II)

Of the 106 patients, 55 were primarily treated conservatively and 51 surgically (Table 7). The injury was bilateral in 21 and unilateral in 30 of those surgically treated, and respectively, bilateral in 19 and unilateral in 36 of those conservatively treated. C4/5, C5/6, or C6/7 were the levels most commonly injured, in 93 patients (90%), and the most common fractures were spinous process and laminar (38 surgically and 32 conservatively treated), followed by articular process fractures (22 surgical and 35 conservative). Accompanying cervical injuries were common: 17 surgically and 18 conservatively treated patients had more than one fractured vertebra.

Table 7. Characteristics of the 106 patients. Modified from Koivikko MP, Myllynen P, Santavirta S, Fracture dislocations of the cervical spine: a review of 106 conservatively and operatively treated patients, Eur Spine J 2004; 13:610–616, with permission from Springer-Verlag.

	Primary method of treatment	
	Conservative	Surgical
N (male:female)	55 (45:10)	51 (40:11)
Age, years (range)	43.2 (16–87)	42.8 (16–80)
Trauma, N		
Motor vehicle accident	23	28
Simple fall	10	7
Fall from height	10	6
Diving	3	3
Other	9	7

Diagnosis was delayed for more than 2 days in seven conservatively treated patients (a mean 5 days) and in 11 surgically treated patients (a mean 13 days). The conservative treatment was in 39 patients skull traction (a mean 34 days) followed by a Philadelphia collar (a mean 58 days), in nine patients HTV (a mean 41 days) followed by Philadelphia collar (a mean 46 days), and in seven patients Philadelphia collar alone (a mean 84 days). Of patients in the surgical group, after initial closed repositioning (mean 4.2 days in skull traction, achieving realignment in 27 of 46), 82% underwent surgery within two weeks. After surgery, the Philadelphia collar was worn for 90 days on average. The average hospital stay was 53 days (SD 50 days) for the conservatively treated and 27 days (SD 25 days) in the surgically treated. Median follow-up was 12.4 (3.2–111.8, mean 24.0) months for the conservative treatment group and 11.9 (3.1–41.2, mean 13.8) months for the surgical group.

Among conservatively treated patients, 16 underwent late surgical stabilization because of instability, progression of neurological symptoms, or an unacceptable anatomical result (average 54, SD 40 days, after the trauma and one case 6.5 years following trauma). They had, on average, a 5.1-mm (SD 2.1 mm) re-dislocation and 13° (SD 6°) kyphotic deformity. Six primarily surgically treated patients underwent a second operation for residual instability (0 days, 3 days, 6 days, 41 days, 88 days, and 245 days after initial surgery). Three of the conservatively treated and two of the surgically treated patients died during their primary hospital stay (Table 8).

*Table 8. Number of complications during hospitalization and follow-up. * indicates death from complication. Modified from Koivikko MP, Myllynen P, Santavirta S, Fracture dislocations of the cervical spine: a review of 106 conservatively and operatively treated patients, Eur Spine J 2004; 13:610–616, with permission from Springer-Verlag.*

	Surgical treatment		Conservative treatment	
	Frankel grade		Frankel grade	
	A to D	E	A to D	E
During hospital treatment				
Respiratory complications	4	3	6 **	2
Cardiac complications	1	2 *	2	—
Cerebral infarction	1 *	—	—	—
Deep vein thrombosis	—	1	3	2
Pulmonary embolism	—	—	1 *	1
Urinary tract infection	4	—	4	—
Gastrointestinal complications	1	—	2	1
Decubitus ulcer	—	—	1	—
Recurrent nerve injury	—	—	1	—
Pulmonary air embolism	—	1	—	—
Surgical infection	—	2	—	2
Loosening of pins	—	—	—	2
Disturbance of swallowing	—	2	—	—
Total N of patients at risk	13	38	19	36
Total patient-years in hospital	1.89	1.87	3.78	3.77
After hospital discharge				
Urinary tract infection	3	2	2	—
Cerebral infarction	—	1	—	—
Decubitus ulcer	2	—	1	—
Surgical infection	—	1	—	1
Total N of patients at risk	12	37	16	36
Total patient-years follow-up	12.7	38.9	40.2	55.1

Radiological results are summarized in Table 9. Patients in the surgical group had less displacement on discharge ($p = 0.004$, Mann–Whitney test) and at the end of follow-up ($p = 0.006$ excluding those with late surgical stabilization or a second operation). As to neurological outcomes, of spinal cord-injured patients, 10 of 16 treated conservatively and nine of 12 treated surgically recovered one Frankel grade or more ($p = 0.8$, chi-square test, Table 10). One conservatively treated patient deteriorated from grade B to A. Those who improved, regardless of treatment method, tended to have less displacement on admission (6.9 mm versus 11.8 mm, $p = 0.08$), on discharge (1.3 mm versus 3.1 mm, $p = 0.04$), and at the end of follow-up (1.6 mm versus 2.7 mm, $p = 0.3$).

Ten of 24 surgically treated and four of 21 conservatively treated Frankel E patients with radicular symptoms on admission had persisting radicular symptoms at the end of follow-up ($p = 0.2$, chi-square test). Four surgically treated and 14 conservatively treated patients were suffering from persistent neck pain ($p = 0.01$, chi-square test). Neck pain correlated with displacement on discharge (2.8 mm in symptomatic patients versus 1.9 mm in non-symptomatic patients, $p = 0.04$, Mann–Whitney test), but not with displacement at the end of follow-up (2.6 mm versus 2.2 mm, $p = 0.2$, Mann–Whitney test). Kyphotic deformity did not correlate with neck pain. At the end of follow-up, 25 conservatively and 14 surgically treated patients had 5° or more of kyphotic deformity. Eight conservatively and 13 surgically treated patients showed lordotic deformity of 5° or more. Of the 36 conservatively treated patients who did not have late surgical fusion, 20 developed kyphotic and five developed lordotic deformity.

Table 9. Radiographic data on admission and end of follow-up.

	Primary method of treatment	
	Conservative	Surgical
Vertebral displacement, mm (%VBS)		
Admission	5.6 (24%), SD 3.8	7.0 (30%), SD 4.1
Discharge	2.6 (11.3%), SD 2.1	1.5 (7.1%), SD 1.6
End of follow-up	3.0 (13.0%), SD 2.2	1.6 (7.9%), SD 1.6
End of follow-up, excluding late surgery	2.9 (13.1%), SD 2.2	1.6 (7.7%), SD 1.7
Kyphotic deformity, degrees		
Admission	1.9 (SD 10.6)	4.9 (SD 10.9)
End of follow-up	5.7 (SD 11.1)	1.0 (SD 11.3)

Table 10. Neurological status assessed by Frankel's grading on admission and at end of follow-up. Modified from Koivikko MP, Myllynen P, Santavirta S, Fracture dislocations of the cervical spine: a review of 106 conservatively and operatively treated patients, Eur Spine J 2004; 13:610–616, with permission from Springer-Verlag.

On admission	At follow-up									
	Conservative					Surgical				
	A	B	C	D	E	A	B	C	D	E
A	4			1		1	1	1		
B	1		2				1	1	1	
C					2				1	2
D				1	5				1	2
E					36					37

Non-union in odontoid process type II fractures (III)

A total of 69 patients with odontoid base fractures had been treated with the HTV, preceded by skull traction repositioning (average time of four days, range 0–22 days, n = 41) when needed. The HTV was worn for a mean of 66 days (SD 20 days, range 20–122), followed by cervical collar stabilization for an average of 51 days (SD 35 days, range 14–172). This treatment resulted in solid osseous union in 32 of the fractures (46%). In the remaining 37 patients, conservative treatment resulted in pseudoarthrosis or fibrous union, of which nine cases required surgery.

Non-union was associated with delayed start of treatment, fracture gap > 1 mm, posterior dislocation > 5 mm on admission, and posterior re-dislocation > 2 mm. In anteriorly displaced fractures, extent of dislocation was unrelated to outcome. Posterior tilting (> 20 degrees) of the odontoid process correlated with non-union, although with considerable overlap. Neither duration of skull traction, HTV, nor collar immobilization correlated with outcome, a result likely to be confounded, as patients experiencing non-union are more likely to suffer prolonged immobilization. Simultaneous atlas fractures, SCI, accompanying injuries, trauma energy (high-energy versus simple fall), and gender were unrelated to non-union. Patients aged over 65 had a higher incidence of non-union and, simultaneously, more often had posteriorly dislocated fractures.

To control for such confounding effects, a binary logistic regression analysis was conducted: Posterior dislocation (> 5 mm on admission or > 2 mm on discharge), fracture gap (> 1 mm), and delayed onset of treatment (> 4 days) were significantly associated with outcome (III Table IV; $p < 0.0001$, model chi-square statistic). By these three covariates, the model predicted 84.1% of the outcomes correctly (III Table V). Age, sex, and posterior angulation did not improve the model’s accuracy (likelihood ratio test statistic). In the cohort studied, solid osseous union occurred in 26 of 31 patients presenting none of the four risk factors (> 5 mm posterior displacement, > 2 mm posterior re-displacement, fracture gap or delay of more than 4 days), and conversely, union occurred in only 6 of 38 patients with 1 to 3 of these risk factors. A prediction without the variable indicating re-dislocation—a risk factor unknown at the time of the clinical decision on treatment method—yielded acceptable precision with 26 of 36 patients presenting with none of these three risk factors having union, compared with 6 unions in 33 patients presenting with 1 to 3 risk factors.

MDCT of odontoid process type IIA fractures (IV)

Of the 26 injuries, 14 were non-comminuted type II fractures and 12 had additional type IIA free fragments: one free fragment in five and two or more fragments in seven. Four of them had minor comminution with fragments up to 3 mm in size, seven had moderate comminution with fragments exceeding 3 mm in size, and one had severe comminution with fragmentation of more than half of the odontoid process base. The odontoid process was dislocated posteriorly in ten, anteriorly in one, and non-displaced in one of the type IIA fractures, compared with eight posteriorly, one anteriorly, two laterally, and three non-displaced ordinary type II fractures. In four posteriorly dislocated type IIA fractures, free fragments were found within the fracture gap: anteriorly in two, posteriorly in one, and centrally in one of them. Inter-observer agreement was acceptable (Kappa 0.77), with inter-observer disagreement in three cases. All three cases were finally classified, by consensus, as ordinary type II fractures.

Fractures in ankylosing spondylitis (V)

Of 2282 consecutive cervical spine MDCT scans, 18 (0.8%; 16 male, 2 female; age 41 to 87 years, mean 57) patients met the inclusion criteria, with 17 diagnosed with AS from 6 to 40 (mean 27) years prior to the trauma. In one patient, symptomatic for 7 years, diagnosis had not been established, but imaging findings and clinical history were characteristic for AS.

The most common trauma mechanism was a simple fall (Table 11). Half of the 18 patients had SCI; 16 (89%) complained of neck pain, one was unconscious, and one's clinical symptoms were undocumented.

Table 11. Trauma mechanism in 18 AS patients.

Trauma mechanism	N of patients (%)
Simple fall	13 (72%)
Bicycle accident	2 (11%)
Fall from height	2 (11%)
Fall from a horse	1 (6%)

MDCT detected CSI in 17 (94%) cases: a total of 31 fractures and one facet joint subluxation (Table 12). Seven patients had multiple fractures, in two of them non-contiguously; 14 (78%) had transverse fractures extending through all three columns—through the vertebral body in eight and transdiscally in six. The transverse fracture affected C6, or adjacent intervertebral spaces (C5/6 or C6/7), in 12 (85%) of the cases.

In addition to those spinous process fractures which were part of a transverse fracture, MDCT detected eight spinous process fractures—with a transverse fracture in the vicinity of each of them.

Table 12. Fractures detected by MDCT.

	N of fractures
Transverse fracture	14
Spinous process fracture	8
Odontoid process, type I	1
Odontoid process, type II	2
Jefferson's fracture	2
C2 laminar fracture	1
Ankylosed C0/1 fracture	1
Transverse process fracture	1
Articular process fracture	1
Facet subluxation	1

Plain radiographs, available for 12 (67%) cases, detected 12 (48%) of the 25 fractures detected by MDCT (Table 13). Cervical spine MRI, obtained within 0 to 3 days (mean 0.9 days) for 11 (61%) patients, showed 12 (60%) of 20 fractures detected by MDCT in the same patients (Table 13). Radiography or MRI detected no additional fractures. MRI revealed SCI in a total of eight (72%) and spinal epidural hematoma (SEH) in three (27%) patients.

Table 13. Number of CSIs detected by radiography versus MDCT, and MRI versus MDCT.

	X-ray / MDCT	MRI / MDCT
Transverse fracture	3 / 9	9 / 9
Spinous process fracture	4 / 6	0 / 5
Odontoid process, type I	1 / 1	—
Odontoid process, type II	2 / 2	2 / 2
Jefferson's fracture	2 / 2	0 / 2
C2 laminar fracture	0 / 1	—
Ankylosed C0/1 fracture	0 / 1	—
Transverse process fracture	0 / 1	—
Articular process fracture	1 / 1	0 / 1
Facet subluxation	0 / 1	1 / 1

DISCUSSION

In CSI of the lower cervical spine, both anterior and posterior surgical stabilization have certain benefits but also drawbacks (Hadley et al. 2002f): An anterior approach allows removal of bone and disk material from the spinal canal and a rigid stabilization targeted to the anterior column, while spinal cord injury, or iatrogenic anterior SEH are potential, but rare complications. Reduction of facet joints can be difficult or impossible from this approach (Allred and Sledge 2001), and anterior plating is insufficient in the most severe distractive flexion injuries (Henriques et al. 2004). In contrast, posterior approaches allow relatively safe open reduction of facet joints and reconstruction of posterior column stability (Allred and Sledge 2001), but also require reasonably intact posterior bony structures for fixation. Removal of herniated disk material, which may have herniated into the spinal canal during the open reduction, is impossible from a posterior approach, and spinal canal decompression by laminectomy would increase undesirable instability. Whether anterior or posterior stabilization should be favored in cases without herniated disk material necessitating anterior surgery is controversial (Hadley et al. 2002f).

Timing of cervical spine surgery may play a critical role in treatment of SCI patients. Experimental studies on animals have demonstrated the benefits of early (within hours) decompression (Guha et al. 1987). While the safety of surgery within the first days after trauma has been questioned, an increasing amount of evidence supports the safety of early surgery and—most importantly—supports the hypothesis of early surgical decompression and stabilization as aiding recovery from SCI (Mirza et al. 1999).

Burst and flexion teardrop fractures (I)

A prospectively planned and randomized study comparing conservative and surgical treatment of these injuries would probably produce more detailed and reliable information about their drawbacks and benefits. For ethical reasons such a study will apparently remain undone. The present study compared, retrospectively, the anatomical and clinical results of two modes of treatment. As methods and instrumentation in spine surgery are developing rapidly (Omeis et al. 2004, Moftakhar and Trost 2004), Study I already offers a historical perspective on the issue, and is not valid for other types of instrumentation. The results, however, give realistic insight into the question whether such injuries should be treated surgically. Both burst and flexion teardrop fractures were included, because clinically and radiologically these injuries are often indistinguishable, with cases representing morphological patterns of both burst and flexion teardrop fractures. Therefore both fractures may, in theory, represent opposite ends of a continuum of compression-flexion injuries, with axial compression being the major loading in the former and compression-flexion in the latter.

Assessment of the neurological status was performed with the Frankel scale, which lacks the accuracy and sensitivity of more sophisticated methods but is clinically well accepted; in addition, improvement by only one grade represents a truly noticeable improvement in a patient’s capabilities.

In these injuries, post-injury radiographs correlate poorly with and underestimate the violation of the spinal canal during impact (Chang et al. 1994). This agrees with our finding of virtually no correlation between SCI severity and the extent of displacement seen on admission. The results of this study support the hypothesis that the severity of a SCI is determined not only by the magnitude of the initial impact and immediate tissue injury, but also by the severity and duration of cord compression (Guha et al. 1987), and associated secondary events such as hypoxia, enzymatic lipid peroxidation (Bracken et al. 1990), and apoptosis (Emery et al. 1998) injuring neural tissue. In addition to decompression—either closed or open surgical type—inhibition of secondary cellular injury processes are realistic targets for future therapeutic intervention. Of the pharmacological treatments, methylprednisolone and monoganglioside (GM-1 ganglioside) have received the most attention, both tested in relatively large clinical trials (Bracken et al. 1990, Geisler et al. 2001). However, none of the pharmacological agents investigated have yet proven sufficiently safe and efficient to justify their more widespread clinical use or to establish treatment guidelines (Hadley et al. 2002b). Because recent data suggest that the neurological benefit from methylprednisolone is only modest (Fehlings 2001a) and the number of subjects in our study receiving the medication was small, it is not surprising that we found, between those who received methylprednisolone and those who did not, no difference in neurological recovery.

In the present study, neurological improvement was associated with proper reduction of retropulsed vertebral body fragments. Closed repositioning by skull traction in theory rely on the tensile force applied to the posterior longitudinal ligament, which will in turn push retropulsed fragments forward. The closer to a straight line (which is approximately equal to the normal posterior vertebral body alignment in skull traction) that the posterior ligament runs, the larger will be the required tensile force—a phenomenon demonstrated experimentally in cadavers (Harrington et al. 1993) and also often seen clinically. In our study, surgical reduction, decompression, and bone grafting yielded a better restoration of the spinal canal anatomy and a corresponding better neurological recovery. Late kyphotic deformities were less frequent in the surgically treated patients than in those treated conservatively, as seen previously (Fisher et al. 2002).

The results indicate that anterior surgical treatment of these injuries is as safe as conservative treatment: The number and profile of complications were similar between groups and more closely associated with the severity of the SCI than with mode of treatment. Deep venous thrombosis was more common in conservatively treated patients, but retrospectively we cannot distinguish whether this is a true difference between the treatment methods, or merely a result of improved antithrombotic prophylaxis used in the surgically treated.

Fracture dislocations (II)

Fracture dislocations, a heterogeneous group of flexion, flexion-distraction, and flexion-rotation injuries causing both ligamentous and osseous injury (Hadley et al. 2002f), are often complicated by spinal cord and root injuries. Fracture dislocations have been treated successfully by a number of methods. As the biomechanical instability in these injuries is mainly caused by disruption of posterior column structures, the most logical therapeutic intervention is restoration of posterior column integrity. However, compared to many of the newer stabilization methods, the interspinous wiring carries definite disadvantages: It is ineffective in injuries with multiple, contiguous spinous process or laminar fractures. Similarly, the tendency of wires to cut through the spinous processes imposes requirements on bone quality which may be less of a problem in the Bohlman triple-wire modification of the technique, with bone grafts and a tension band construct. Biomechanically, the stability of posterior triple-wire fixation is comparable with that of lateral mass plating (Mihara et al. 2001). Interspinous cervical fusion is generally safer than posterior sublaminar techniques and is technically less demanding than anterior approaches or posterior lateral mass plating; the posterior approach allows, when necessary, a relatively safe open reduction of facet joints.

In addition to biomechanical considerations, the choice of either anterior or posterior surgery is also influenced by spinal canal compromise with bone fragments, epidural hematoma, or herniated disk material. Traumatic disk herniation and hematoma (Eismont et al. 1991, Harrington et al. 1991) is relatively common in these injuries (Vaccaro et al. 2001) and is a probable confounding factor in a retrospective study setting of this kind, since most of the cases were treated before the era of MRI. The first 1.5T MRI was not installed in Helsinki University Central Hospital until 1989. Medullary impingement by herniated disk material manifesting at the moment of vertebral reduction is a rare (Grant et al. 1999, Vaccaro et al. 1999) but much feared complication. MRI can identify herniated disk material, and this complication can, to at least to some extent, be avoided by the choice of anterior surgery. However, imaging takes time and, especially in cord compression, time can be a critical factor (Fehlings et al. 2001b). Whether MRI is necessary before repositioning or whether immediate repositioning is safest is controversial (Allred and Sledge 2001, Nockels 2001, Hart et al. 2002). MRI either prior to or after repositioning can disclose not only complicating herniated disk material and hematoma (Rizzolo et al. 1991, Vaccaro et al. 2001), but can also provide fundamental information as to SCI severity (Flanders et al. 1990), vital for choice of treatment.

Results of Study II show correlation between the degree of reduction of displacements and neurological recovery. Anatomical results after surgery were better than those after conservative treatment, but were inconsistent in that surgery did not per se guarantee neurological recovery; neurological recovery occurred also in a number of conservatively treated patients with less than perfect anatomical results. Conversely, some patients, despite perfect surgical restoration of the spinal canal dimensions, failed to improve. Overall, neurological outcomes were quite similar in both treatment groups. Experimental evidence suggests that the severity of SCI is determined not only by the force of the initial impact, but also by severity and duration of persisting compression (Guha et al. 1987, Fehlings et al. 2001b) and subsequent secondary cell-level damage to neural tissue (Bracken et al. 1990, Emery et al. 1998). Theoretically, the force of the initial impact may be the main determinant of the outcome in fracture dislocation. Here, however, the association between initial displacement, i.e., the displacement seen on arrival, and neurological outcome was weak. Correlation of post-injury radiological deformity in cervical spine fracture dislocations with occlusion of the spinal canal during impact has not been established, but in burst fractures post-injury imaging underestimates the spinal canal occlusion occurring during impact (Chang et al. 1994, Wilcox et al. 2003).

The number and profile of complications were similar in both treatment methods studied, although conservatively treated patients had a longer average stay in hospital. They also suffered more often from late deformities, instability, and chronic neck pain. Finally, almost a third (29%) of the conservatively treated injuries required late surgery because of an unacceptable anatomical result with residual instability or progression of neurological symptoms. That deep venous thrombosis was uncommon in surgically treated patients, could be related either to the shorter immobilization required after surgical treatment or to improved antithrombotic prophylaxis.

Odontoid process fractures (III, IV)

The Anderson and D'Alonzo classification (1974) is well established and valuable in predicting outcome and guiding treatment for odontoid fractures. Fractures of the odontoid tip (type I) and those extending through the vertebral body (type III) heal well by conservative treatment. By conservative HTV treatment fractures of the odontoid base (type II) often, however, fail to unite. Results of Study III suggest a correlation of delayed onset of treatment, a fracture gap, posterior displacement, and re-displacement with such failure. Comminuted type II fractures (type IIA), with additional free fragments present in the fractured odontoid base, are less stable and rare. Results of Study IV, however, indicate that such fractures may be more common than previously appreciated.

Non-union is common in type II fractures, possibly due to the small fracture surfaces in a synovial environment lacking periosteum, in conjunction with the inadequacy of orthoses in stabilizing the fracture (Schatzker et al. 1975, Southwick 1980). Avascular necrosis is uncommon in these fractures, as blood supply to the odontoid fragment is not disrupted (Govender et al. 2000). Non-union has been associated also with advanced age (Pepin et al. 1985) and delayed treatment (Govender et al. 2000). Fractures displaced more than 5 or 6 mm are prone to non-union (Clark and White 1985, Hadley et al. 1989, Greene et al. 1997), and some evidence exists that posterior displacement of fractures may be an even more important risk factor (Stoney et al. 1998, Govender et al. 2000). The results of the present study support this latter hypothesis, as displacement exceeding 5 mm was associated with non-union only in posteriorly displaced fractures. Close contact of fracture surfaces and sufficient immobilization are necessary for the endosteal healing process of type II fractures (Schatzker et al. 1975), making it logical that both a fracture gap and posterior re-displacement—neither of which has been studied—were associated with non-union.

In contrast to posterior displacement, posterior re-displacement, or fracture gap—all easily recognized from conventional radiographs—angular tilting of the odontoid fragment gives little indication of fracture instability, as the range of normal angulation of the odontoid is wide (Doherty and Heggeness 1995). In the present study, in a multivariate analysis taking into account the other risk factors, angulation had no predictive potential. Similarly, age, although correlating with non-union in univariate analysis, was unrelated to outcome in multivariate analysis. None of the studies reporting age as a risk factor (Pepin et al. 1985, Ryan and Taylor 1993, Polin et al. 1996, Stoney et al. 1998, Govender et al. 2000) has used multivariate control for the confounding effects of the other risk factors. In the present study, delayed treatment (> 4 days) correlated with non-union, in harmony with earlier reports of success rates rapidly declining with delayed start of treatment: HTV success rate has been only 25% after a delay of one week (Dunn and Seljeskog 1986) and 20% after two weeks (Ryan and Taylor 1993). Govender et al. (2000) reported a faster decline in success rates with other orthoses (Minerva cast or sterno-occipital immobilizer), with a 76% union success in patients presenting within 48 hours, 44% in those presenting within 4 to 7 days, and 0% in those presenting after one week.

In studies on odontoid fracture treatment, several interesting—and controversial—questions deserve consideration: Should the objective be 100% osseous union, or is fibrotic union acceptable? In such cases, how much residual instability can be tolerated? To avoid late instability potentially manifesting as chronic pain or a rare but feared myelopathy, the most logical objective is bony union of every fracture. In this study fibrotic non-unions—many of which may have been clinically acceptably stable—were rated as non-unions, as reflected by the reported HTV union rates: only 32 (46%) showed solid osseous fracture healing. In the remainder, HTV treatment often resulted in clinically sufficiently stable fibrous union, with surgery eventually needed by only 9 (13%) of the 69 patients. It should be emphasized that because Study III focused on attempted conservative treatment, patients subjected to primary surgical fusion were excluded. Thus, our series does not represent a general type II odontoid process fracture cohort admitted to a trauma clinic.

The significance of the additional IIA subtype—proposed by Hadley in 1988—is uncertain, as only a few of such injuries have been reported, with primary surgical treatment recommended for type IIA fractures (Hadley et al. 1988, 1989, Koc et al. 2001). With modern thin-section imaging such as MDCT used in Study IV, morphology of odontoid fractures can be seen in greater detail, and accordingly, classification can be more precise. As the degree and severity of comminution in the type IIA fracture pattern has not been precisely defined, it is probable that the present and future development of MDCT will have an impact on what percentage of odontoid fractures are diagnosed as type IIA. Thus, the definition of the type IIA fracture may need refinement to take into account this evolution in imaging methods. The effect on treatment success of fragment size, fragment interposition within the fracture gap, and degree of comminution certainly warrants further investigation.

Fractures in ankylosing spondylitis (V)

Despite CSI incidence in otherwise healthy individuals being relatively low after blunt trauma, the price of missing a CSI can be enormous. Establishing a correct diagnosis, positive or negative, in every injury before any further neurological deterioration is a major challenge both for the attending clinician and the radiologist. Hence, the term "cervical spine clearance," i.e., clinical and, whenever necessary, radiological exclusion of clinically significant CSI, has gained popularity. Instead of measuring accuracy of a diagnostic test in all types of patients and all kinds of CSI, the current trend (Hanson et al. 2000a, Hoffman et al. 2000, Mower et al. 2001, Morris and McCoy 2004) is toward a problem-based approach, with clinical scenarios in which CSI is diagnosed or excluded, for instance, in cervical spine clearance after low-energy blunt trauma in asymptomatic patients, or exclusion of CSI in high energy-traumatized, unconscious patients. The present study assessed the performance of MDCT in detection of CSI in advanced AS. MDCT was capable of detecting CSI more reliably than was plain radiography or MRI and, in addition, MDCT was superior in demonstrating fracture morphology.

CSIs in AS often differ considerably from those in non-AS spines: In AS the fracture line, usually axially oriented in the anterior vertebral body or transdiscally, may extend cranially for one or two vertebral levels in the middle and posterior column structures—regardless of any anatomical intersegmental limits. We found MPR images crucial in interpreting these often subtle and complex findings. The high rate of positive findings demonstrated in this series of AS patients also indicates that a very low index of suspicion of fracture, even after minimal trauma, is justified.

It is known that spinal fractures are more common in AS than in the general population (Detwiler et al. 1990) and can result from minor trauma such as a simple fall (Alaranta et al. 2002). Fractures have a predilection for the lower cervical spine and cervicothoracic junction (Weinstein et al. 1982). Most CSIs in this study were located in C6 or in the adjacent intervertebral spaces. While in the general population one-third of CSIs are located in the upper (C0–C2) cervical spine (Goldberg et al. 2001), in AS, C0–2 injuries are not as common (Detwiler et al. 1990), as confirmed by our results. In AS, odontoid process type II and III fractures are uncommon (Ozgocmen and Ardicoglu 2000), and type I fractures, extremely rare in the general population (Goldberg et al. 2001), have not been previously reported in AS. Similarly to earlier studies (Broom and Raycroft 1988, Detwiler et al. 1990), a high incidence of SCI was evident.

Technically flawless radiographs in AS patients are difficult to obtain, with difficulties in both positioning and bone tissue contrast; due to the rigidity of the ankylosed spine and shoulders it is difficult and often impossible to obtain good quality radiographic images of the usual injury site, the lower cervical spine. Opacity and anatomic distortion of the osteoporotic spine cause difficulties in detection of non-dislocated fracture lines. With long lever arms present in the rigid spine, even hair-thin, non-displaced fractures carry the potential of causing severe SCI. In AS patients, the incidence of SCI is approximately 11.4 times as great as in the general population (Alaranta et al. 2002). As radiography is of limited value in the detection of unstable injuries, it is not an advisable method for CSI screening in advanced AS. Conventional CT is safe and fast and provides valuable information on fracture delineation and spinal canal compromise (Weinstein et al. 1982, Fox et al. 1993, Goldberg et al. 1993, Wu and Lee 1998, Taggard and Traynelis 2000). MRI was superior in the assessment of SCI, and it detected severe CSI more reliably than did plain radiography. Many AS patients are, however, ineligible for MRI: Difficult monitoring of the patient, the length of the examination, incompatible anesthesiology equipment, and skull traction devices or pacemakers are common problems. AS patients with severe kyphosis may not fit properly into the coil or even into the closed-bore MR scanner. In such cases, MR systems with an open design are, however, a feasible option.

CONCLUSIONS

I Burst and flexion teardrop fractures

Compared to conservative treatment, anterior decompression and Caspar plating of burst and flexion teardrop fractures provides superior decompression of the spinal canal and more rigid fixation, promoting the healing of SCI.

II Fracture dislocations

The transition from conservative treatment to surgical stabilization by bone grafting and interspinous wiring resulted in better anatomic end results, with similar complication rates. An appropriate reduction in dislocations correlated with neurological recovery. Late neck pain, correlated with residual displacement, was more common in conservatively treated patients.

III Non-union in odontoid process type II fractures

Type II odontoid fractures with a fracture gap > 1 mm, a posterior displacement > 5 mm, delayed start of treatment > 4 days, or a posterior re-displacement > 2 mm are unlikely to achieve bony union by HTV.

IV MDCT of odontoid process type IIA fractures

In type II odontoid fractures, subtle comminution is more common than previously reported.

V Fractures in ankylosing spondylitis

In advanced AS, MDCT is superior to plain radiography or MRI in detection of CSI and provides more information on fracture morphology, whereas MRI provides valuable information on associated SCI and soft-tissue injury.

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