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MULTIDETECTOR COMPUTED TOMOGRAPHY OF SPINAL AND PELVIC FRACTURES

with special reference to polytrauma patients

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Academic Dissertation

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All of science is nothing more than the refinement of everyday thinking.

Albert Einstein

ABSTRACT

Serious injuries of the spine and pelvis are common in level I trauma centers, and are usually the result of high-energy accidents such as motor vehicle accidents (MVA) or falls from a height, but increasingly also sports and recreational accidents. Even presumably minor accidents can result in serious injury depending on the injury mechanism. The risk of acquiring a fracture is also tied to possible predisposing factors such as a weakened bone structure in osteoporosis, or an increased stiffness of the spine in ankylosing spondylitis.

Spinal injuries have a potential for catastrophic, life-altering consequences, because they are associated with spinal cord injury (SCI). A missed or inappropriately managed spinal injury can result in secondary SCI or progression of the initial damage. But also pelvic fractures pose a serious threat, as there are large-caliber blood vessels, nerves, and the lower urinary tract in close proximity to the pelvic bones. An acute bleeding into the pelvic area can remain clinically silent for an extended amount of time due to circulatory compensation processes.

Exclusion of these occult injuries by imaging techniques is therefore imperative in order to detect a serious injury as early as possible and administer appropriate treatment. Time-, space-, and cost restraints as well as the patient's stability limit the application of imaging modalities in the 'golden hour' of trauma resuscitation, which is arguably the most critical phase for the patient's outcome. The optimal choice of imaging methods is therefore crucial. But also the knowledge of injury patterns and demographic risk factors contributes to the correct diagnosis of a serious injury.

This thesis focuses on injury patterns of the spine in conjunction with high-energy accidents, as well as demographic patterns and the optimal choice of imaging modality. It consists of five publications with a total of 2375 cases, covering a time frame from January 2001 to September 2009. There is special emphasis on vertebral burst fracture, which is the most common fracture in the

thoracolumbar area, and which has furthermore a high potential for SCI due to its unstable nature. Also the bony pelvis as an extension of the spine receives special reference.

According to our results, serious spinal injury as a result of blunt trauma occurs in all age groups and independently of gender, and even minor trauma energies can result in serious trauma. Trauma energy does have an influence though, as the incidence of spine fractures increases with increasing falling height, and burst fractures and spine fractures on multiple levels become more frequent.

But also other blunt trauma mechanisms had multiple spine fractures in up to 32 % of cases, whereof 29 % were non-contiguous. Burst fracture was seen on multiple levels in 10 % of cases, with 50 % being non-contiguous. The frequent occurrence of vertebral fractures and especially burst fractures on non-contiguous levels makes imaging of the whole spine necessary in conjunction with high-energy accidents, especially in obtunded patients.

Radiography demonstrates unstable vertebral fractures with acceptable accuracy, particularly in the lumbar spine (LS). Summation of overlapping tissue in these areas makes the identification of the hall marks of an unstable facture difficult, which can lead to an injury being missed, or wrongly classified as stable. Neurological deficit was most frequent and serious in the CS.

In the pelvic area, radiography detected only 55 % of fractures diagnosed by multidetector computed tomography (MDCT), and in 11 % findings were false negatively normal. Additionally, Tile classification of fractures was correct in 59 % of injuries, whereas the subtype was correct in only 14 %. The pelvis was false negatively classified as stable in 40 % of cases.

Sport and recreational accidents had an overall incidence of injury of one in five, of which 71 % were considered to be serious. The three most common types of serious injury were intracranial injury, fractures of facial bones, and vertebral injuries. The most common accident mechanisms were bicycling, horseback

riding, and team ball sports, with bicycling causing most frequently serious injury.

In conclusion, it is recommended using MDCT to rule out serious injury of the spine and pelvis in adult victims of high-energy accidents of all age groups and both genders, especially in regard to multilevel injuries and injuries of the cervical spine. Even in presumably minor trauma, a high level of suspicion is required, and MDCT should be employed if the clinical finding is uncertain. MDCT is fast, cost-effective, and demonstrates injuries of the spine and pelvis unambiguously, benefiting the trauma patient's outcome.

Keywords: Trauma, skeletal-axial, MDCT, radiography, burst fracture, noncontiguous fracture, pelvic fracture.

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 **Bensch FV**, Kiuru MJ, Koivikko MP, Koskinen SK. Spine fractures in falling accidents: analysis of multidetector CT findings. Eur Radiol 2004; 14(4): 618-624.

II Their ME, **Bensch FV**, Koskinen SK, Handolin L, Kiuru MJ. Diagnostic value of pelvic radiography in the initial trauma series in blunt trauma. Eur Radiol 2005; 15(8): 1533-1537.

III **Bensch FV**, Koivikko MP, Kiuru MJ, Koskinen SK. The incidence and distribution of burst fractures. Emerg Radiol 2006; 12(3): 124-129.

IV **Bensch FV**, Koivikko MP, Kiuru MJ, Koskinen SK. Measurement of spinal canal narrowing, interpedicular widening, and vertebral compression in spinal burst fractures: plain radiographs versus multidetector computed tomography. Skeletal Radiol 2009; 38(9): 887-893.

V **Bensch FV**, Koivikko MP, Koskinen SK. MDCT findings in sports and recreational accidents. Acta Radiol 2011; 52(10): 1107-1112.

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ABBREVIATIONS

ACS	American College of Surgeons
ALARA	As low as reasonably achievable
ALL	Anterior longitudinal ligament
AP	Anteroposterior
AS	Ankylosing spondylitis
ATLS	Advanced trauma life support
CI	Confidence interval
CIN	Contrast media-induced nephropathy
CMSC	Contrast media safety committee of the European Society of Urogenital Radiology
CNS	Central nervous system
CR	Computed radiography
CS	Cervical spine
CSI	Cervical spine injury
CT	Computed tomography
CTJ	Cervicothoracic junction
DAI	Diffuse axonal injury
DR	Digital radiography
ER	Emergency room
FAST	Focused assessment with sonography for trauma
GCS	Glasgow Coma Scale
GFR	Glomerular filtration rate
HU	Hounsfield unit
ICD	International Statistical Classification of Diseases
LS	Lumbar spine
MDCT	Multidetector computed tomography
MDP	Methylene diphosphonate
MOF	Multiorgan failure
MPR	Multiplanar reformation
MRI	Magnetic resonance imaging
MVA	Motor vehicle accident

NEXUS	National Emergency X-radiography Utilization Study
NI	Nuclear imaging
PACS	Picture archiving and communication system
Pixel	Picture element
PLL	Posterior longitudinal ligament
SCI	Spinal cord injury
TLICS	Thoracolumbar injury classification and severity score
TLJ	Thoracolumbar junction
TS	Thoracic spine
US	Ultrasound
Voxel	Volumetric picture element

INTRODUCTION

Injuries of the spine and the directly dependent structures such as the skull and pelvis are a common occurrence in trauma centers everywhere. In healthy individuals, these injuries result mostly from high-energy accidents (Light 2009, Levy 2006). Predominant trauma mechanisms might differ slightly from one part of the world to another, as there is a higher emphasis on safety regulations in developed countries especially concerning motor vehicles and workplace environment but also higher availability of high speed transportation and directly related increase in traffic density, as well as commonly higher powered engines. Also, industrial development increases the risk of high-energy trauma through more elaborate construction and engineering, a major cause of injury especially in young workers (Holte 2012).

The most common causes for serious trauma with spinal involvement are high-energy accidents related to motor vehicle accidents (MVA) and falls (Light 2009, Levy 2006). In the United States, there have been 10.8 million traffic accidents in 2009, the most recent year for which statistical data is available, resulting in 35.900 fatalities (U.S. Census Bureau 2011). In 2010, 6072 traffic accidents with personal injury were recorded in Finland, in which 272 people were killed and 7673 injured (Suomen Tilastokeskus 2011). The number of traffic related fatalities has consistently decreased in both countries in recent decades, owing most likely to improved standards of safety as well as primary care. Nevertheless, with the popularization of extreme sports, contact sports, and other activities prone to high-speed/high-impact events on a professional as well as on an amateur or leisure level, another major risk factor for serious trauma has to be taken into consideration (Gill 2008).

Skull and the vertebral column contain and protect the central nervous system (CNS) consisting of the brain and spinal cord, which is arguably the most critical organ system to be cleared in an emergency setting after stable circulation and respiration has been established (ACS 2007). The pelvic ring is the anatomical extension of the spine, protecting organs and large vessels of the pelvic region and providing stability as well as transfer of forces from the lower extremity (Drake et al. 2010). Primary diagnosis focuses on these structures in an effort to decrease immediate mortality and permanent disability. A major role of imaging in the acute phase is the exclusion of fractures posing a threat to these structures either through direct mechanical damage or indirectly through occult bleeding or swelling of soft tissues. For instance the iliac arteries run in close proximity to the pelvic bones, which are at high risk of fracture during high-energy accidents, especially in conjunction with frontal collision MVAs. Since even serious hemorrhage inside the pelvis can remain clinically silent for an extended amount of time, reliable and prompt diagnostics of the pelvic structures is imperative (Dalinka 1985, Giannoudis et al. 2007).

Before the advent of computed tomography (CT), the cornerstone of diagnostics was conventional radiography, and later x-ray tomography, where x-ray source and film cassette are being moved in opposite directions relative to the patient, which leads to an image focused on a predetermined plane while blurring all other layers. Both share the fundamental flaw of offering very little soft tissue contrast and therefore poor accuracy in the diagnosis of hemorrhage or internal organ damage. Even the good contrast between bony and soft tissues of this techniques often fails to demonstrate the exact anatomy of a complex injury, and might require at least additional projections, putting patients with unstable injuries further at risk and delaying treatment.

When CT was introduced in 1972, the new modality offered previously unheard of bone- and soft tissue-contrast, especially in conjunction with opacification agents (i.e. intravenous contrast media). Additionally, exact and direct spatial localization of findings became suddenly possible. Initially slow and scarce, CT technology evolved, prices dropped, and overall availability increased, which contributed to its quickly becoming the gold standard for exclusion of life threatening internal injuries in trauma patients. The introduction of multidetector CT (MDCT) in the late 1990’s further reduced acquisition time and improved image quality, while exposure to ionizing radiation, the only major disadvantage of CT, is dwindling without compromising diagnostic power due to hard- and software as well as acquisition protocol improvements (Prolok 2003, Geijer 2006).

Magnetic resonance imaging (MRI) offers far superior soft tissue contrast, and also highly diagnostic images of bony structures, but the technique's inherent limitations, such as numerous contraindications, long acquisition time, susceptibility to artifacts, or the need to remove all ferromagnetic objects from the patient, have prevented it so far from becoming a major alternative to MDCT in a trauma setting. It is, however, used in the evaluation of neural soft tissue after trauma, such as in the event of suspected spinal cord injury (SCI) or diffuse axonal injury (DAI) (Lammertse et al. 2007).

The introduction of multi-energy CT into clinical practice represents the next step in the evolution of CT, which offers a combination of some of the advantages of MDCT and MRI while further limiting drawbacks, which will likely benefit trauma patients. Dual energy CT for example offers the possibility to calculate pre-contrast images of decent quality from contrasted images, thus eliminating the need for additional pre-contrast series. At this point, however, there is still very little evidence on this topic.

Diagnostic ultrasound plays only a minor role in acute trauma, and is exclusively employed as FAST (focused assessment with sonography for trauma) to exclude free peritoneal fluid indicative of peritoneal hemorrhage as part of the primary evaluation process. Its sensitivity for retroperitoneal hemorrhage or parenchymal organ injury is rather low (Harris 2000).

Nuclear imaging (NI) primarily detects changes in metabolic activity with high sensitivity by measuring radionuclide uptake of specifically targeted tissues. Unfortunately, these changes are highly unspecific and require additional imaging to specify precise location and nature of a lesion. Also, changes do not necessarily appear instantaneously, but correspond to reactive processes. Therefore, NI does not play a major role in complete trauma imaging.

REVIEW OF THE LITERATURE

High-energy trauma

General considerations

High-energy trauma occurs in industrialized countries primarily in conjunction with traffic and falling accidents (Light 2009, Levi 2006), and is the leading cause of death and disability in the young adult population (Hu et al. 1996).Also, sports activity poses a risk for catastrophic injury, especially in the craniocervical area (Gill 2008). The mechanism of injury is usually deceleration from high momentum (Smith 2005). Management of polytrauma patients follows ideally the guidelines of advanced trauma life support (ATLS) (Kortbeek et al. 2008).A fair number of injuries of the head and spine, amongst others, go unnoticed by the attending physicians (Light 2009). Additionally, there is always a risk of pulmonary embolism in major trauma and fat embolism in conjunction with fractures of long bones and pelvis (Habashi 2006).

Level I trauma centers

According to the definition of the American College of Surgeons (ACS2007), trauma centers are categorized by their capacity and treatment options into levels from level V for the most basic facilities to level I for a center which is fully equipped to respond to any emergency, even with numerous seriously injured patients simultaneously. A level I trauma center offers around the clock, i.e. 24/7 in-house service in orthopedic surgery, neurosurgery, anesthesiology, and radiology with adequate staff, equipment, and facilities to provide immediate diagnosis and operative or interventional treatment in these disciplines (ACS 2007). Additionally, there must be a full spectrum of surgical specialists available (orthopedic surgery, neurosurgery, cardiac surgery, thoracic surgery, hand surgery, microvascular surgery, plastic surgery, obstetric and gynecologic surgery, ophthalmology, otolaryngology, and urology). Also supporting staff ranging from specialized nurses to physiotherapy and laboratory services has to be available at all times (ACS 2007).

Anatomical considerations

The spine

The spine is the main support structure of the axial skeleton, bearing the weight of the cranium and upper extremities as well as translating this weight to the pelvic girdle and lower extremities. It normally consists of a total of 26 vertebrae (7 cervical, 12 thoracic, 5 lumbar, 5 sacral and 4 coccygeal), where the sacral and coccygeal vertebrae are commonly fused into a single bone, i.e. the sacrum and coccyx, respectively. The spine's flexibility and ability to rotate is provided by a complex system of fibrocartilaginous (intervertebral disks) and synovial joints (facet joints), all of which have a very limited physiological range of movement. The sum of these limited movements over a number of segments allows nevertheless for a high degree of flexibility while ensuring stability and protection for the spinal cord and nerves exiting through the intervertebral foramina. Additional passive support is provided by fibrous ligaments, which run anteriorly and posteriorly along the vertebral column (anterior and posterior longitudinal ligament, supraspinous ligament) or connect the posterior structures of neighboring vertebrae (ligamentum flavum, interspinous ligament). The anterior and posterior longitudinal ligaments are very tough structures with low elasticity, which are connected anteriorly to the intervertebral disk and posteriorly to the vertebral body. The ligamentum flavum and the other posterior ligaments are in comparison more flexible, which prevents protrusion into the spinal canal during extension movement. The term 'ligamentum flavum' (Latin for 'yellow ligament') is derived from this ligament's high content of elastic collagen (elastine), which is yellowish in color. Further active support is provided by the deep (intrinsic) as well as the superficial (appendicular) back muscles. The spine has physiological curvatures, which add to flexibility and increase impact absorption effects. Normally, there is lordotic curvature in the cervical and lumbar spine, and kyphotic curvature in the thoracic spine and the sacrum. In the thoracic spine, the ribs articulate posteriorly with the vertebral body and transverse processes in the costovertebral joints, providing increased torsional and translational stability to the spine (Drake et al. 2010).

Contained within the vertebral canal is the spinal cord, which terminates usually on the level of the first lumbar vertebra as the conus medullaris, and the proximal portions of the distal spinal nerves, the cauda equina. Surrounding the spinal cord and cauda equina is the dural sac containing cerebrospinal fluid, blood vessels, and connective tissue (mostly fat). Because of the neural fibers leaving the spinal cord on every successive segment, the ratio of spinal canal diameter to cord thickness grows the more distally the segment, resulting in more space for pathologic changes inside the spinal canal without necessarily causing neurological symptoms (Drake et al. 2010).

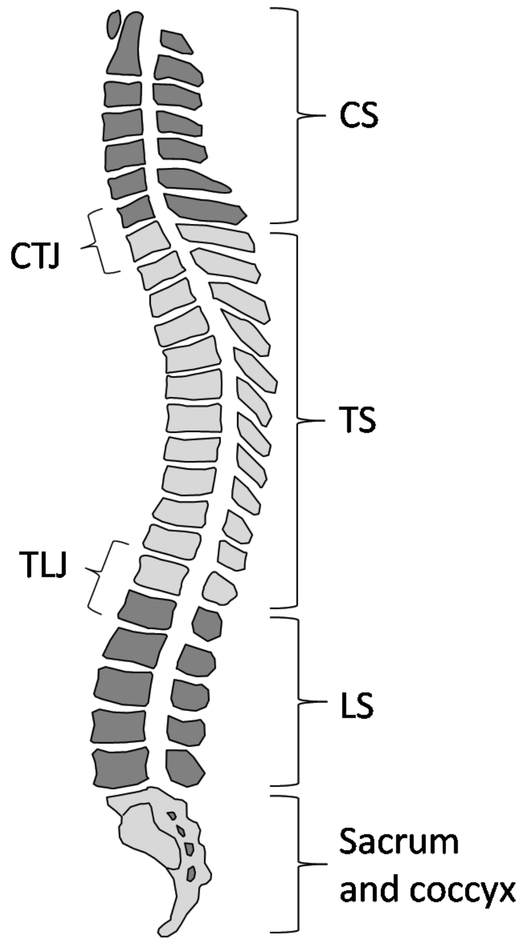

Fig. 1 Areas of the spine. *CS* cervical spine; *TS* thoracic spine; *LS* lumbar spine; *CTJ* cervicothoracic junction; *TLJ* thoracolumbar junction.

Vertebrae

Human vertebrae have a common configuration: A roughly cylinder-shaped vertebral body consisting of cancellous bone inside an outer frame of cortical bone, which is the main weight-bearing structure, and the vertebral arch including pedicles, a spinous process, bilateral transverse processes, and the superior and inferior zygapophysial articular processes, which form the facet joints. The only exceptions to this rule are the first and second cervical vertebrae, which have evolved to allow for rotational movement of the cranium, and the sacral and coccygeal vertebrae, which are usually fused together (Drake et al. 2010).

The anatomical differences of human vertebrae of different spinal segments originate mainly from the orientation of the facet joints. In the cervical spine, facet joints are slightly sloped anteroposteriorly, allowing for flexion and extension. Thoracic facet joints are oriented vertically, which limits flexion and extension but facilitates rotation. Lumbar facet joints are curved and adjacent processes interlock, which limits movement mostly to flexion and extension(Drake et al. 2010). The junctional areas such as the cervicothoracic junction (CTJ) and thoracolumbar junction show an apparent predisposition for injury (Meves et al. 2005), owing to the mechanical strain of connecting two elements with different mechanical properties.

Intervertebral disks

The intervertebral disks are fibrocartilaginous joints (i.e. symphyses), which separate each vertebra from adjacent vertebrae except for the atlantoaxial joint. Each disk consists of a fibrocartilaginous annulus fibrosus, which effectively limits rotation between adjacent vertebrae, and a gelatinous nucleus pulposus, which absorbs axial compression forces. Due to the semifluid consistency of the nucleus pulposus, it can herniate into neighboring anatomical structures like the spinal canal or vertebral bodies through defects of its containment structures, i.e. the annulus fibrosus and vertebral end plates. This can happen as a degenerative change with little pathological significance as for example

Schmorl's hernia. If, on the other hand, sufficiently high impact energies affect the nucleus pulposus, the incompressibility of fluids will cause sudden traumatic herniation through the weakest point of the adjacent structures, which might be further facilitated by degenerative or other pathologic changes (Drake et al. 2010).

The pelvis

The pelvis is a bowl-shaped structure formed by the three-dimensional arrangement of the ilium, the sacrum, and the coccyx. The sacrum is connected to the fifth lumbar vertebra via the presacral joint and to the pelvic bones via the sacro-iliac joints, while both ilia articulate anteriorly with each other in the symphysis pubis. The symphysis pubis is a fibrocartilaginous joint, whereas the sacroiliac joints have both synovial joint and fibrous joint elements, with irregular, interlocking joint surfaces to resist movement, and can become fibrous or even ossified with age. The pelvic joints are stabilized posteriorly by the sacroiliac ligaments and anteriorly by the pubic ligaments, additionally the wedge-shaped sacrum functions much like the stabilizing keystone in a gothic arch. Axial forces from the lower limb are transferred to the spine primarily through the tight sacro-iliac joints. Critical anatomical structures such as the iliac vessels, ureters, and nerves run along the surface of the pelvic bones, putting them at risk of damage in case of a fracture(Drake et al. 2010). Because of its three-dimensional configuration, conventional radiography of the pelvis is naturally impeded by large amounts of summation from bony structures, soft tissues, and bowel gas(Harris 2000).

The acetabulum

The hip joint is a simple synovial ball and socket-joint, in which the acetabulum is the cup-shaped socket and the femoral head the ball. The acetabulum lies at the joining of the ischium, pubis, and ilium, as part of the pelvic bone. Superiorly lies the cartilage-covered, crescent-shaped articular (or lunate) surface, while the central and inferior parts are dominated by the acetabular notch, through which blood vessels and nerves enter. For fracture classification and assessment of mechanical stability, the acetabulum is divided according to the Letournel classification into an anterior column containing the anterior acetabulum, iliac wing and superior ramus, and a posterior column containing the posterior acetabulum and the ischium. A sagittal line through the base of the acetabulum defines additionally an anterior and posterior acetabular wall (Fig.) (Harris 2004).The triradiate cartilage separates the ossification centers of the ilium during development, and acts as a bordering structure for the columns (Harris 2004). It eventually fuses and calcifies during skeletal maturation. The roof of the acetabulum consists of compact bone, which acts like a keystone in a gothic arch, stabilizing it and allowing the arch to bear weight. The hip joint is stabilized passively by the iliofemoral and pubofemoral ligaments with a possible contribution by the ligamentum capitis femoris (Bardakos 2009), and actively by the deep and superficial groups of gluteal muscles (Drake et al. 2010).

Vertebral fractures

General considerations and classification

Injuries of the spinal column and spinal cord have been associated with trauma since ancient times (Smith 2005, Breasted 1930), and also the connection between spinal cord interruption and neurological deficit was understood from early on (Singer 1956). Stability is, apart from morphology, extent, and location, the core issue in the assessment of vertebral injuries, as this is the decision point between conservative and invasive treatment, and an injury falsely considered stable might worsen significantly from the initial status due to inappropriate treatment, with potentially catastrophic results. Also, it should be kept in mind that vertebral injuries occur in up to 43% of cases on noncontiguous levels (Atlas et al. 1986), implying exigency for imaging of the whole spine in case of a high-energy trauma or polytrauma, since symptoms of one injury can easily obscure symptoms of potentially more serious additional injuries. Especially in polytraumatized, intoxicated, or unconscious patients, clinical examination alone is not reliable. Also, medical imaging cannot demonstrate all critical injuries if performed suboptimally, which may lead to catastrophic consequences (Levi et al. 2006). The reported incidence of missed spinal fracture after trauma varies between 0.001% and 4.6% (Levi et al. 2006), and delayed diagnosis of cervical spine injury is even estimated at 5-20% with initial conventional radiography (Platzer et al. 2006). A wide range of conditions from metabolic disorders from osteoporosis to malignant bone disease can increase the probability of spinal fractures even after minor trauma, or even under physiological strain. There are various classifications for vertebral injuries with different emphasis on biomechanical, clinical, or outcome parameters available, all of which are useful in clinical practice. The three-column concept (Denis 1984) offers a simple but effective biomechanical model and is widely applicable, even in regard to CS fractures. The vertebra is divided in the sagittal plane into three columns: The anterior column includes the anterior two thirds of the vertebral body and the anterior longitudinal ligament, the middle column the posterior third of the vertebral body and the posterior longitudinal ligament, and the posterior column the pedicles and vertebral arch structures with the posterior ligamentous complex. Compromise of any two columns suggests an unstable injury (Fig. 3). Other classifications include sub-axial injury classification and severity scale (SLIC; Vaccaro et al. 2007) for CS injuries, and for thoracolumbar injuries Magerl’s classification (Magerl 1994) or thoracolumbar injury classification and severity score (TLICS; Vaccaro et al. 2005). These incorporate additional information from clinical status and trauma mechanism, and thereby create numerous subgroups, for some of which statistical analysis can be hard or even impossible due to small case numbers even in large samples. SLIC and TLICS provide high reproducibility and are considered superior in clinical practice, while Magerl’s classification is still most commonly used (Young 2010).Nevertheless, using Denis’ concept, the vast majority of vertebral injuries can be reliably described and evaluated for stability regardless of fracture level, and it was found to serve the purpose of this retrospective study best. Following is a more detailed review of the injuries most significantly associated with this study.

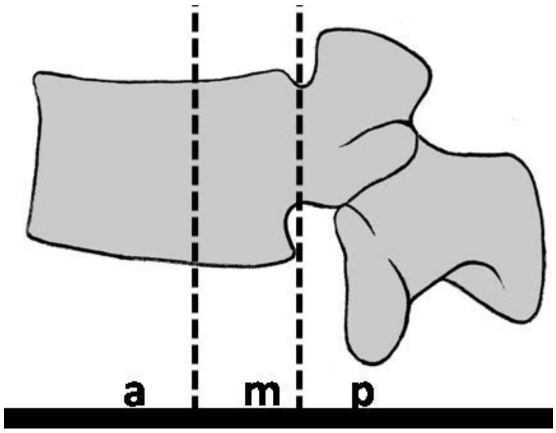

Fig. 2 Vertebral columns according to Denis' classification (Denis 1984). *a* anterior, *m* middle, and *p* posterior column.

Burst fracture

First described in 1963 (Holdsworth 1963), the vertebral burst fracture is most common amongst thoracolumbar fractures (Dai et al. 2008) and results typically from direct axial load to the spine, in reaction to which the nucleus pulposus of an adjacent intervertebral disc herniates through the vertebral end-plate with high pressure and causes disruption of the vertebral body from within due to the incompressibility of fluids. The hallmark of this injury is a retropulsed bone fragment from the posterior cortex of the vertebral body, which is dislocated into the spinal canal and might cause compression or even disruption of neural structures (Saifuddin et al.1996). The final resting place of this fragment at the time of imaging does not allow for conclusions about the maximum extent of the injury at the time of the trauma, as it will be partly relocated due to the tension of the posterior longitudinal ligament and the mass of the contents of the spinal canal (Wilcox et al. 2002 and 2003). In a controlled laboratory setting, canal occlusion during impact was shown to correlate with impact energy, while the amount of occlusion measured on CT images showed no correlation to either parameter (Wilcox et al. 2003). Burst fractures can extend into any structure of the vertebral body even until total comminution, but might also be underappreciated and mistakenly classified as stable injuries due to very subtle findings, possibly leading to delayed complications, which could be life-altering. Therefore, imaging modalities play a central role in the diagnosis of this injury, with MDCT as the gold standard from early on (Kim et al. 1999). Often, the diagnosis of a burst fracture is possible on conventional radiography by means of signs such as increased interpedicular distance, posterior vertebral body compression, or even direct visualization of the retropulsed bone fragment. Nevertheless it is hard or even impossible to effectively exclude this injury based on conventional radiography, especially in areas with profuse summation from soft tissues and bony structures like the CTJ and thoracic spine. Nevertheless, the overall clinical long-term outcome of thoracolumbar burst fractures has been reported to be predominantly favorable (Moller et al. 2006, Shen 2001).

Compression fracture

The etiology of this injury, also called wedge compression fracture for its characteristic morphology, is usually axial load in conjunction with flexion stress, which results in the compression of the anterior column, and possibly a lateral component due to additional lateral flexion during impact. The middle column is intact, and the spinal canal is not compromised. Facet joints are congruent and articulate normally, and the posterior ligament complex is typically intact, providing rotational and translational stability. Due to the injury mechanism, in which the middle column acts as a pivot point, there might be signs of overextension in the posterior column, while dorsal fracture indicates a more complex injury. The non-complicated compression fracture, which is considered stable, is the main differential diagnosis to the aforementioned unstable burst fracture, and the distinction between these injuries poses a challenge especially on conventional radiography. Because of its lack of instability and spinal canal compromise, vertebral compression fracture is usually managed conservatively (Harris 2000).

Posterior column fractures

Isolated fractures of the vertebral arch usually result from overextension or pull from ligaments, muscles, or connective tissue, which are mainly attached to spinous and transverse processes, but also to laminae and pedicles. An isolated injury of the posterior column does not normally affect stability, as the posterior arch is not a main weight-bearing structure. Dislocations of both facet joints are considered unstable, as these are necessarily associated with a dislocation of the anterior and middle column, usually in the form of a ruptured intervertebral disk. Except for direct compression trauma, fragments from posterior column fractures dislocate only very rarely into the spinal canal, as they are being held in place by ligaments or even pulled away by the attached muscles. For nondislocated fractures, management is largely conservative (Harris 2000).

Other fractures

Fracture dislocations usually result from a complex trauma mechanism including any combination of axial compression, hyperflexion or -extension, rotational, and shearing forces, affecting all three columns and disrupting the continuity of supporting structures as a whole. These injuries are usually unstable and severely dislocated, and the probability of detection will therefore be high even on conventional radiography. Additionally, patients are likely to present with severe neurological symptoms indicating at least the level of the highest spinal injury. Fracture dislocations occur frequently in the highly mobile cervical spine, where the consequences of spinal cord compromise are most severe. Flexion teardrop fractures fall in this category and should not be confused with extension tear drop fracture, which occurs mainly in the lower cervical spine and represents an avulsion fracture of the insertion of the anterior longitudinal ligament (ALL), which is more benign and normally considered stable. Fracture dislocations might even present without damage to the bony structures as rupture of the ligamentous complex and intervertebral disc structures, such as for example riding or locked facet injuries without bony fracture (Harris 2000).

Fractures of C1 and C2 are different in morphology because of the particular anatomy of these vertebrae. C1 does not have the vertebral body which is seen in normal vertebral anatomy. Instead, its shape is dominated by two lateral masses which articulate with the occipital condyles and C2, and which are connected by an anterior and posterior bony arch. Atlanto-occipital dislocation is a rare and often overlooked unstable injury, which is especially hard to demonstrate on conventional radiography, but can have life-threatening consequences. Isolated occipital condyle fracture, on the other hand, is considered a stable injury. The term Jefferson fracture describes a burst fracture of C1, consisting of an unstable bilateral disruption of the anterior and posterior arch, which usually results from direct axial load. Jefferson fracture may also occur unilaterally. Fractures of the odontoid process (or dens) of C2 come in three categories: avulsion of the tip of the dens (type I) and fractures of the base of the dens extending into the vertebral body (type III), both considered stable, and fractures through the base of the dens (type II), which are considered unstable and are the most frequent fractures of the odontoid process. Another typical and usually unstable injury of C2 is traumatic spondylolysis (also known as hangman's fracture), which comprises bilateral pedicle fracture due to hyperextension. Additionally, as mentioned previously, extension teardrop fracture has a tendency to affect C2 (Harris 2000).

Horizontal split injuries (also known as Chance fracture) occur mainly in the thoracolumbar spine as flexion injuries over a pivot point, classically in conjunction with MVAs and lap seat belts. These injuries can extend through the vertebral body, the intervertebral disk, or both (Chance 1948). Classically, all three columns are disrupted making the injury unstable, and might present with features of a burst fracture (Bernstein et al. 2005).

Furthermore, there are pathologic conditions from metabolic to rheumatic diseases, which can increase the likelihood and extent of a fracture such as osteoporosis, or even cause atypical patterns of spinal fractures as in ankylosing spondylitis (Hanson 2000, Koivikko et al. 2004, Koivikko 2008). The latter progresses into a condition called 'bamboo spine', where first the outer fibers of the intervertebral disks and then the disks themselves ossify, effectively fusing adjacent vertebrae together. In this condition the vertebrae behave like a single unit rather than separate elements, which allows fractures to extend over multiple levels without respect for border structures. Due to the overall stiffness of this fused spine, the overall incidence of fractures is markedly increased even after minor trauma, and fractures are likely to traverse multiple levels (Samartzis 2005).

Pelvic fractures

General considerations and classification

Pelvic fractures occur mainly in early adulthood due to high-energy trauma, or in the elderly as a result of relatively minor trauma, such as falls from a low height, usually from a standing position (Melton et al. 1981). Pelvic injury is considered the third most common cause of death in conjunction with MVAs (Dalinka 1985, Giannoudis et al. 2007). A significant amount of energy is required to disrupt the ligaments or bones of the pelvic ring in a healthy individual. Therefore, most pelvic injuries in a younger population result from high-energy trauma like MVAs or falling accidents. Pelvic fractures present frequently with associated soft tissue injury due to the considerable forces involved. This can lead to tissue necrosis and occasionally sepsis, which may develop to severe sepsis or multiorgan failure (MOF), the main causes of late mortality in unstable pelvic fractures (Kataoka 2009). Critical soft tissue structures such as large-caliber blood vessels, nerves, ureters, and the urethra run close to the surface of the pelvic bones, putting them at risk for injury, including severe hemorrhage. A fracture of the pelvic bones can itself be the source of hemorrhage due to the usually large surface area of the wound. While an unstable fracture of the pelvic ring is usually clinically apparent, can even large, active bleedings in the pelvic area remain clinically silent for an extended amount of time due to circulatory compensation processes. Pelvic injury has been found to be associated with higher mortality in trauma patients (Sathy et al. 2009), even though the most common causes of death in the early phase are intra- and extrapelvic hemorrhage or associated cranial injury, while multiorgan failure or systemic infection predominate in later stages (Kataoka et al. 2009).

The Tile classification of unstable pelvic injuries (Pennal et al. 1980) (Figure 3) offers an easily applicable model based on fracture morphology and stability, which also considers force vectors. Type A injuries are considered stable, type B injuries rotationally unstable but vertically stable, and type C injuries both rotationally and vertically unstable or involving the acetabulum. Type B and C injuries usually require fixation, while type A injuries are managed non-operatively. With pelvic girdle stability being the main parameter regarding treatment options, the Tile classification provides a comprehensive model providing the essential information in this respect. A viable alternative in clinical practice is the Young-Burgess classification of pelvic injury (Young 1996, Burgess 1996), which expands upon the Tile concept and categorizes injuries according to trauma mechanism while also recognizing combined force vectors, i.e. lateral compression, anteroposterior compression, vertical shear, or a combination of forces, each with Grades I-III with respect to associated injuries.

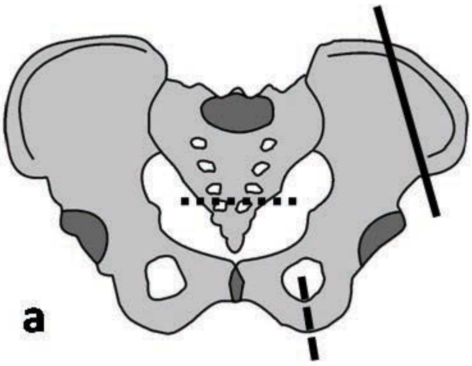

Fig. 3a Tile A stable pelvic fractures. A1 avulsion (solid line), A2 stable pelvic ring fracture (dashed line), and A3 transverse sacral or coccygeal fracture (dotted line).

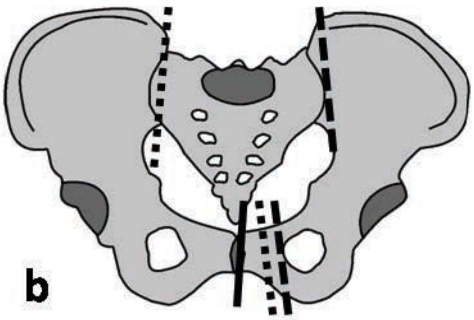

Fig. 3b Tile B rotationally unstable, vertically stable fractures. B1 symphysis disruption (solid line), B2 ipsilateral lateral compression (dashed line), and B3 contralateral lateral compression (dotted line).

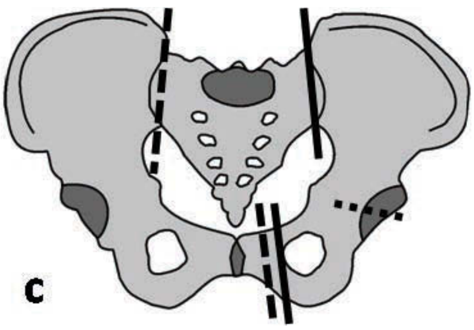

Fig. 3c Tile C rotationally and vertically unstable fractures. C1 ipsilateral anterior and posterior pelvic fracture (solid line), C2 contralateral anterior and posterior pelvic fracture (dashed line), and C3 any pelvic fracture with associated acetabular fracture.

Imaging options

General considerations

The same principle as for medical treatments and interventions applies also to diagnostic imaging: To maximize benefit to the patient while minimizing negative side effects, which is implied in the widely used acronym ALARA (as low as reasonably achievable, in regard to radiation dose). At the same time, imaging should be as cost-effective as possible, but still provide sufficient information while avoiding overdiagnosis of nonessential findings. In a trauma setting, optimal positioning of the patient and the equipment is often limited by time and space restrictions, which directly affects conventional radiography image quality. Patient compliance might be poor due to shock, pain, or intoxication, increasing the likelihood of motion artifacts. Longer acquisition times allow these effects to accumulate. Furthermore, monitoring and assisted respiration equipment might impede patient positioning, be visible on images, or cause artifacts, and can furthermore prevent the patient from being examined for example by MRI due to ferromagnetic components or sensitive circuitry. All this adds to the pressure of having to establish the essential diagnoses as quickly as possible in order to achieve the best possible care for the patient. There is no general consensus over an optimal algorithm for clinical and radiological examination of the spine in the literature, but most authors agree that a clinical decision rule is required for proper evaluation (NEXUS, Platzer et al. 2006). Even if there is no doubt about the necessity for imaging in acute trauma, overuse of medical imaging has become an increasingly important issue with growing capacities and growing overall costs, emphasizing the importance of the application of proper protocols for diagnosis including clinical examination as well as a sensible choice of imaging options (Hendee et al. 2010, Chou et al. 2011). Effective dose per capita from medical imaging varies between 0.01 mSv and10 mSv for CR and between 2 mSv and 20 mSv for CT (Mettler 2008). Ionizing radiation from imaging studies causes significant damage on DNA level depending on dose, raising the probability of malignancy and germ cell damage, while low dose radiation effects might even be underestimated (Beels et al. 2011). This is especially critical when imaging women of fertile age who either are or might potentially be pregnant, which cannot always be reliably excluded in trauma victims because of common factors such as unconsciousness or shock. In case of a confirmed pregnancy, imaging options should be chosen even more carefully. Radiation exposure of the embryo or fetus over a threshold of 100 mSv or higher can result in prenatal death, intrauterine growth restriction, mental retardation or diminished intelligence quotient, organ malformation and childhood cancer (ICRP 2000, McCollough et al. 2009). Nevertheless, this threshold is not reached even with repeated abdominal MDCT examinations (ICRP 2000). Adhering to the principle of ALARA, exposure of the developing fetus should be kept to a minimum or avoided altogether by employing radiation-free techniques such as diagnostic ultrasound. In the event of major trauma or other acutely life-threatening conditions such as for example pulmonary embolism, excluding life-threatening injuries of the mother by MDCT is nevertheless the most favorable course of action also regarding the wellbeing of the unborn infant, even though irradiation of the lower abdomen can possibly be avoided (Patel et al. 2007, McCollough et al. 2009).

Computed tomography

The term ‘tomography’ is derived from Greek and means literally ‘imaging by slices’, which refers to the obtaining of transverse sections of the object inside the scanner. This is achieved by an x-ray tube rotating on a longitudinal axis around the object to be scanned, with a detector on the opposite side recording attenuation of each beam. The object moves along this axis through the scanner, either slice by slice or continually, depending on the scanner’s construction. Today’s CT scanners are usually of the third generation type, which uses a tube and detector array rotating synchronously on opposite sides of the patient, thereby making helical (also known as spiral) CT possible. The latter process results in a continuous helical data set rather than a series of two-dimensional images. Raw data acquired from CT is being calculated into a two-dimensional image by a processing unit using tomographic Radon transformation, a method of mathematical back projection, along with several algorithms for improving image quality, such as edge sharpening or noise filtering. In standard CT scanning, two-dimensional or pixel (picture element) resolution is determined by the raster resolution, while three-dimensional or voxel (volumetric picture element) resolution is determined by raster resolution and the thickness of the acquired slices. In helical CT, slice thickness is determined by the reconstruction increment used to calculate slices from the continuous data volume. Attenuation values of voxels are standardized according to the Hounsfield scale using water and air as references. Hounsfield units (HU) always correspond to material density and are also comparable between different scanners. Because the range of gray scales employed is significantly higher than the human eye's capability to distinguish, certain ranges of attenuation values are being emphasized by a process called windowing to make image interpretation possible. Furthermore, tissue contrast can be enhanced by introducing contrast media, which increases attenuation values depending on tissue perfusion. This also makes dynamic evaluation of metabolic activity of tissues possible (Prokop 2003, Harris 2000).

So far there have been four generations of computed tomography scanners since the presentation of the first functional CT scanner by Godfrey Hounsfield in 1972, and development of basic CT technology was already completed by the end of the 1970s. MDCT is the current standard, and dual- or multi-energy CT is an up and coming technology. Both of the latter technologies and their basic concepts have in fact been suggested by Hounsfield himself already at an early stage of CT development (Hounsfield 1973), showing that the great potential of CT technology was already well understood, even though the more advanced technologies had yet to be realized. The principal evolution of CT technology was complete by the end of the 1970's, with the next milestones being the introduction of helical CT in 1989 and MDCT in 1998 (Prokop 2003). Multidetector helical computed tomography is widely accepted as the gold standard for exclusion of serious trauma to the spine (Antevil et al. 2006, Tomycz et al. 2008, Prokop 2003) as well as cranium and pelvis. It has been found to be the most sensitive, specific, and cost-effective modality for bony injuries (Antevil et al. 2006), but does not perform as well in the detection of isolated ligament injuries (Diaz 2005). Unstable injuries are reliably demonstrated by MDCT even in obtunded patients, and further examination after an initial MDCT without pathologic findings is largely considered obsolete (Harris 2008, Tomycz 2008). CT is recommended for all severe pelvic injuries to fully appreciate anatomy and extent of injuries (Dalinka 1985). Integration of whole-body MDCT in the primary evaluation of polytrauma victims is recommended (Huber-Wagner et al. 2009), and makes further imaging of spine and pelvis unnecessary (Smith et al. 2009). Because of the continuous data set provided by helical MDCT it is possible to create high-quality multiplanar reconstructions (MPR) in any plane with isotropic voxels (Prokop 2003). Additionally, high quality three-dimensional surface renderings can be calculated from this data set, which used to be time-consuming and useful almost exclusively for planning surgery (Kösling 1997). With advances in image processing and post-processing three-dimensional volume rendering has become a valuable adjunct to two-dimensional series, and is a tool routinely used for estimating spatial relations of bones and soft tissues, as well as for the routine planning of surgery (Geijer 2006).

The only major disadvantages of CT compared to other imaging modalities are its inherent higher radiation dose for the patient, and the inability to demonstrate soft tissues like ligaments or the contents of the spinal canal sufficiently (Geijer 2006). With the increasing availability and application of CT comes an increased amount of exposure to ionizing radiation. In the United States, the average exposure of an individual was 3 mSv in 2006, marking a more than sevenfold increase since the early 1980s. 36 % of this overall exposure and 75 % of overall medical exposure can be attributed to medical CT and NI examinations (NCRP Report 2008), with CT examinations being far more common than NI. CT of the abdominal and pelvic area is a major contributor to this exposure because it is associated with the largest radiation dose amongst CT examinations (Marin 2011). Use of CT has grown exponentially in recent years in the United States, which results from increased imaging frequency for ‘classic’ indications for CT imaging, as well as from new indications (Larson et al. 2011). Refinement of imaging protocols and evolution of CT technology contribute to a decrease of exposure from CT examinations in recent years, which is why CT is increasingly replacing conventional radiography in the primary evaluation of trauma also of the extremities or conditions like urinary tract concrements (McCollough et al. 2009). With low-dose algorithms available, the radiologist not only has to consider radiation dose, but also economic aspects. Acquisition time, for example, remains largely constant with low-dose protocols, but interpretation time might increase (Marin 2011). Even though this subject is heavily disputed, a definitive causal relationship between CT radiation exposure and increased cancer risk could not be established so far (Marin 2011).

Iodine contrast media

In order to provide information about blood vessel and tissue integrity, organ perfusion, and sites of active bleeding, trauma CT of the body is routinely performed using iodine-based contrast media. CT without intravenous contrast medium is not considered adequate in a trauma setting for its lack of the above-mentioned information from soft tissues. Intravenous contrast media pose themselves a risk to the patient, albeit a relatively minor one. This risk stems mostly from nephrotoxicity and direct adverse reactions to iodine or inactive components. Glomerular filtration rate (GFR) as a measure of kidney function cannot usually be established before administration of trauma victims because of time constraints, and predisposing factors for nephrotoxic effects in a patient’s anamnesis can remain unnoticed. Serum creatinine is instead considered the critical parameter, since its plasma level is directly related to renal elimination, while still dependent on overall muscle mass and therefore only an approximate indicator of renal function. Contrast-medium induced nephropathy (CIN) is a condition, in which, according to the Contrast Media Safety Committee of the European Society of Urogenital Radiology (CMSC), “an impairment in renal function (an increase in serum creatinine by more than

25 % or 44 µmol/l) occurs within three days following the intravascular administration of a contrast medium in the absence of an alternative etiology" (Morcos et al. 1999). Patients at risk for CIN are those with decreased renal function (GFR <45 ml/min/1.73 m^2 before intravenous administration), with any condition that might impede circulation/perfusion or reduce plasma volume, such as diabetes, congestive heart failure, old age, or dehydration, as an additional risk factor. Risk for CIN increases also with contrast agent osmolality and total volume administered (Stacul et al. 2011).

Adverse reactions to iodine contrast media arise mainly because of the medium's osmolality, which is higher than that of plasma and acts therefore as an irritant throughout the body (Sicherer 2004, Schabelmann 2010). Further causes for an adverse reaction could be inactive ingredients or components (Sicherer 2004). Iodine itself is not an allergen, and the reaction to it is not immune-mediated. Without an immune-mediated reaction, there can furthermore not be an immune memory, i.e. sensibilisation. Pre-existing allergies or asthma cause an elevated risk for an adverse reaction, which is connected to a general atopic disposition rather than allergic cross-reactions (Sicherer 2004). Especially the popularly cited cross-reaction with shellfish allergy is a myth. Neither shellfish allergy nor asthma increases the risk of an adverse reaction to iodine-based contrast media more than any other allergy or related condition (Schabelmann 2010).

Radiography

From the first systematic studies of x-rays by Wilhelm Conrad Röntgen in 1895 until the present day, conventional radiography dominates primary diagnostics in hospitals around the globe. High availability, quick imaging, and low costs contribute to the popularity of this imaging modality. Traditionally, conventional radiography requires the correct placement of a photographic film cassette on the opposite side of the patient from the x-ray tube to be exposed and later developed. With the advent of computed radiography (CR), the photographic film was replaced with a reusable plate containing photostimulable phosphorous, from which a laser scanner reads the image data. This concept was further improved upon with the introduction of digital radiography (DR), where the image is directly read from a digital detector, thereby further reducing the time between exposure and the final image in the electronic archive (picture archiving and communications system, PACS). With current technology, radiation exposure of patients is reasonably low and image quality very high, which are the main reasons why this modality is still sporadically being advocated as a viable primary method to exclude spinal injury, if performed correctly and in conjunction with a proper clinical status. Nevertheless, authors also recognize improved injury detection rates by using MDCT (Platzer et al. 2006). While contrast between bony structures and soft tissue is exceptional in conventional radiography, it is impossible to reliably distinguish soft tissues from each other without additional means of contrast, limiting its application. Interpretation of radiographic images is especially demanding in areas of summation of overlying structures. Details of complex, three-dimensional arrangements like the pelvis can be lost, or whole areas of the image remain non-diagnostic such as the lower cervical spine in lateral projection from summation of the shoulder girdle (Amin et al. 2005), which can at least partly be alleviated by additional series such as the swimmer’s view, or pelvic outlet projections. This problem was addressed by the invention of conventional tomography, where x-ray source and film are being moved in opposite directions during exposure, thereby putting a predetermined plane into sharp focus and blurring all other layers. This technique remained a cornerstone of diagnostic imaging until it was made obsolete by the advent of CT in 1972 (Prokop 2003). Measurements on conventional radiographs are neither reliable as absolute units nor in proportion, since there is an inherent amount of geometric distortion due to the cone-shaped x-ray beam, which lets structures appear larger the closer they lie to the x-ray source and the farther away from the detector.

Magnetic resonance imaging

There is an ongoing debate about the role of MRI in the acute trauma setting. Even though MDCT is generally considered the gold standard of primary imaging in serious trauma of patients with neurologic symptoms or altered mental status (Tomycz 2008), some authors advocate routine application of acute phase MRI to clear the cervical spine in addition to MDCT. While MRI might not be immediately available, they recommend continuous immobilization until SCI or instability is definitely excluded using MRI. Its higher sensitivity and specificity for ligamentous, soft tissue, and osseous edema indicating injury, suggests that MRI is the true reference standard (Schoenfeld 2010, Lammertse 2007, Amin et al. 2005). Also, it has been suggested that conventional radiography is neither sufficiently sensitive nor specific in the detection of pelvic fractures, and that additional MRI is recommended to optimally exclude pelvic injury (Kirby 2009), whereas CT has been the long-standing standard (Dalinka 1985). In an acute trauma situation, it may be impossible to exclude potential contraindications for MRI such as ferromagnetic foreign bodies, or non-removable medical apparatus such as pacemakers or cochlear implants due to missing patient data. Communication with the patient is likely to be limited due to unconsciousness, pain, shock, medication, or even dementia, the latter especially in elder patients. Monitoring and respiratory equipment containing ferromagnetic parts have to be removed prior to imaging. Setup and imaging take an extended amount of time compared to MDCT. All this might compromise patient care in the critical initial time slot, the ‘golden hour’, which is why MRI remains at this time a supporting imaging modality in emergency care largely reserved for the evaluation of neural soft tissue or ligamentous trauma, rather than a primary imaging modality. Also budget, capacity, and availability restrictions limit the implementation of MRI.

Ultrasound

In early trauma management and evaluation, diagnostic ultrasound (US) plays an important role as focused assessment with sonography for trauma (FAST) for the early detection of free peritoneal fluid, which indicates occult hemorrhage, or rupture of the bowel or bladder. FAST is also useful in detecting fluid inside the pericardium and pleural spaces, but cannot reliably demonstrate retroperitoneal fluid or parenchymal organ laceration. Beyond FAST, US has no major application in early trauma management (Harris 2000).

US is based on the reflection of sound waves on tissue interfaces. Electric energy is converted into sound waves and vice versa by piezoelectricity. US travels almost without interference in fluids, but does not penetrate bone. Sound waves are reflected completely on interfaces between tissue and air, which makes gas-filled bowel loops an obstacle for imaging the structures behind them. For these reasons, US has a limited sensitivity for detection of injury. Nevertheless, US can be repeated without any restrictions because of its lack of ionizing radiation. Furthermore, US machines are usually highly mobile, which allows for easy application in the emergency department, or even in the operating room (Harris 2000).

AIMS OF THE STUDY

The purpose of this study is to

(I) determine spinal injury patterns and demographics in falling accidents,

(II) evaluate standard imaging modalities in pelvic blunt trauma,

(III) evaluate injury patterns and demographics of burst fractures of the cervical and thoracolumbar spine,

(IV) evaluate imaging modalities for burst fractures of the cervical and thoracolumbar spine, and

(V) evaluate injury patterns and demographics in sports and recreational accidents

seen in patients referred to a level-one trauma center.

MATERIAL AND METHODS

Patients

General

As the only level one trauma center for the capital area of Helsinki as well as the area of Uusimaa, Töölö hospital has a basic patient population of about 1.4 Million in an area covering 8929 km^2 at the time of this study, making it one of the largest trauma centers in Europe. All polytrauma, neurosurgical and complicated orthopedic cases are referred primarily to Töölö hospital. Patients included in this study were selected by reviewing all emergency MDCT requests over the time spans of the papers included in this study issued by the emergency room physicians in PACS, starting from the installation of the first MDCT scanner in Töölö hospital in August 2000. Also data regarding accident mechanism as well as demographic data such as gender, age, and clinical findings were retrieved from each patient's electronic files, or paper archive where necessary. A total of 2375 patients (1549 male; 65 %) were included in this study, some of which presented up to two times with unrelated trauma, and being therefore included as separate cases. Except for publication V, children below the age of 16 were excluded, since they are taken primarily to the Children's Hospital. Only as an exception, children are admitted to Töölö hospital if there are clear signs of CNS damage likely requiring neurosurgical intervention, or severe orthopedic trauma.

Falling accidents (I)

The time frame for this study is between August 2000 and September. All patients who had suffered a falling accident and were examined by MDCT in the initial phase were included in this study. A total of 237 patients (184 male, age range 16-86 years, mean age 42 years) met the inclusion criteria.

Pelvic trauma (II)

The time frame for this study is between August 2000 and January 2004. Inclusion criteria were blunt trauma, anteroposterior pelvic radiography in the initial trauma series, and a whole body MDCT in the initial phase, which were met by 1386 patients (874 male, age range 16-91 years, mean age 41 years).

Burst fractures (III) and (IV)

Studies III and IV include patients admitted between August 2000 and June 2003 with blunt trauma and one or more vertebral burst fractures confirmed by MDCT in the initial phase of the injury. For study III, only patients primarily admitted to and imaged at Töölö hospital were taken into account. In study IV, we also included patients who were initially examined and imaged in peripheral hospitals, and who were transferred as emergencies to Töölö hospital for further treatment. An additional inclusion criterion for study IV was conventional radiography of the vertebral injury in the initial phase (i.e. before administration of corrective treatment). 152 patients (112 male, age range 16-79 years, mean age 39 years) met the inclusion criteria for study III, while 108 patients (78 male, age range 16-79 years, mean age 39 years) met the inclusion criteria for study IV.

Sports and recreational accidents (V)

Inclusion criteria for this study were an accident resulting from sports or recreational activity with either clinical symptoms or sufficiently high trauma energy to require MDCT of the head, spine, or torso to exclude serious injury. From January 2001 to September 2009, 492 patients (301 male, age range 2-76 years, mean age 34 years) met these inclusion criteria.

Methods

General

During the time of this study, three different MDCT scanners were in use at Töölö hospital: from August 2000 to November 2008, a four-slice Light-Speed QX/i; from October 2007 to September 2009, the LightSpeed VCT 64, and from October 2008 to September 2009, the LightSpeed VCT Select 32. All scanners are manufactured by GE Medical Systems, Milwaukee, WI, USA. Our institution's trauma MDCT protocols are presented in Table 1. Coronal reformats and 3D surface renderings of complex injuries are performed routinely. All radiographs used in study II and 83% of radiographs in study IV were obtained using a computed radiography (CR) unit (Agfa ADC 70).The remaining images of study IV were taken at peripheral hospitals, where a wide range of different equipment is being used. The PACS system used was IMPAX, Agfa-Gevaert N. V., Mortsel, Belgium. Statistical analysis was done using SPSS versions 11, 12, and 15 (SPSS Inc., Chicago, IL). For all parts of this study, two radiologists interpreted MDCT and radiographic images retrospectively and by consensus.

Protocol	Slice thickness (mm)	Interval (mm)	kV	mA	Reformats	Reformat slice thickness (mm)	Reformat interval (mm)
Head	0.625	0.32	120	320	ax	2.0	2.0
					cor	4.0	4.0
Facial bones	0.625	0.32	120	40	ax	1.25	1.25
					cor	2.0	2.0
					sag	2.0	2.0
Cervical spine	0.625	0.3	120	120	ax	1.25	1.25
					sag	2.0	2.0
Torso*	0.625	0.4	120	500	ax	2.5	2.5
					cor	4.0	4.0
					sag	2.0	2.0

Table 1 Routine trauma MDCT protocol as of 09/2011. * *Routine use of iodine-based intravenous contrast agent (concentration: 350 mg / ml; infusion speed: 3 ml / s; amount: bodyweight in kg +15 ml, delay 25 s (thorax) and 65 s (abdomen))*

The vertebral column was divided into four functional units: (a) C0 to Th1 (cervical spine); (b) Th2 to Th11 (thoracic spine); (c) Th12 and L1 (thoracolumbar junction); and (d) L2 to S1 (lumbar spine). Fractures were categorized and stability determined according to Denis' three column-approach (Denis 1984). To estimate severity of neurologic injury while retaining comparability also in smaller patient subgroups, a modified scale according to Frankel's classification of neurological function (Frankel et al. 1969) was employed as follows (Table 2): 0 for no neurological symptoms (Frankel grade E), 1 for slight neurological symptoms like tingling and local loss of surface sensitivity (Frankel grade D), and 2 for severe trauma like para- or quadriplegia

(Frankel grade A to C). Cases with values of 1 and 2 were considered clinically significant in regard to neurological deficit.

Frankel Grade		This study
A	complete paralysis	2
B	only sensory function below injury level	2
C	incomplete motor function below injury level	2
D	fair to good motor function below injury level	1
E	normal function	0

Table 2 Frankel's classification of spinal lesions (Frankel et al. 1969)

Falling accidents (I)

MDCT images were evaluated for spinal trauma, trauma location, fracture type, and whether fractures were at multiple levels. Fracture types were divided into four categories: (a) burst fracture; (b) compression fracture; (c) posterior column fracture; and (d) other fractures. Additional data was acquired regarding falling height, and whether the subject had accidentally fallen or jumped on purpose. Correlations were calculated using simple linear regression.

Pelvic trauma (II)

Radiographic images were interpreted first, followed by MDCT. MPR was done when considered necessary. Studies were evaluated by anatomical region as follows: (a) proximal femur; (b) superior and inferior ramus; (c) pubic symphysis; (d) acetabulum; (e) ilium; (f) sacroiliac joint; (g) sacrum; and (h) vertebral body of L5. Injuries to the pelvis were categorized using the Tile classification of pelvic injuries (Pennal et al 1980; Table 3).

Type	
A	**stable pelvic fracture**
A1	avulsion fracture
A2	nondisplaced pelvic ring fracture
A3	transverse sacral or coccyx fracture
B	**rotationally unstable, vertically stable fractures**
B1	symphysis pubis disruption
B2	lateral compression injury, ipsilateral
B3	lateral compression injury, contralateral
C	**rotationally and vertically unstable fractures**
C1	ipsilateral anterior and posterior pelvic injuries
C2	bilateral hemipelvic disruption
C3	any pelvic fracture with associated acetabular fracture

Table 3 Tile classification of pelvic injuries (Pennal et al. 1980)

Burst fractures distribution and incidence (III)

Cases were additionally categorized by trauma mechanism into the following groups: (a) falling accidents; (b) traffic accidents; (c) recreational accidents including sports. Linear regression, paired *t* test, and Mann-Whitney rank sum test were employed for statistical analysis using two-sided *p* values.

Burst fractures measurements (IV)

For study IV, measurements in MDCT and radiographs were taken using the PACS system's build-in measuring tools. Vertebral compression and interpedicular widening measurements were compared to the mean of measurements of the vertebrae above and below, and this difference recorded as an absolute value in millimeters, since using percentages would suggest disproportionally large differences for comparatively small findings on this small scale. Spinal canal narrowing was measured in the midsagittal plane at the site of maximum narrowing; vertebral height was measured at the site of maximum compression (Fig. 4). Datasets were compared using Spearman's rank sum test for the whole spine as well as for its functional segments, respectively. A nonparametric test was used since data was not normally distributed in all subgroups.

Sports and recreational accidents (V)

MDCT findings were divided into clinically significant and less significant diagnoses. The former category comprised injuries requiring immediate treatment or hospitalization, and being potentially life threatening or -altering, such as injuries to the central nervous system, or permanent aesthetic damage from an injury to the facial skeleton or peripheral cranial nerves. The latter category comprises injuries not normally requiring any intervention or hospitalization/observation, even if they may cause severe discomfort to the patient, such as non-dislocated fractures of the ribs, or peripheral contusions. Injuries outside the scope of this study (i.e. of the limbs) went unrecorded. Additionally, MDCT studies and injuries were categorized according to their location, i.e. in the area of the head, cervical spine, thoracic spine, lumbar spine, or torso. Subgroups were created according to injury mechanism, i.e. sport or activity leading to the trauma. SPSS 15.0 software (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Statistical tests performed were t-test for unpaired data, one-way ANOVA, Kruskal-Wallis test, and Wilcoxon rank sum test.

RESULTS

General

The precise total number of individual patients being discussed in this study is difficult or even impossible to establish due to overlapping of the populations of its parts. Because of the similar etiologies and same base population but different focus on injuries or trauma mechanisms in overlapping time frames, a number of patients has been recorded on different occasions, or even for the same injury in different parts of this study. However, the total number of all cases recorded was 2378 over a maximum time span of 105 months (January 2001 to September 2009).

Falling accidents (I)

Of the 237 patients included in this study, 211 (89 %) had fallen accidentally, 19 (8 %) had jumped, and in seven cases (3 %) the circumstances remained unclear. A total of 203 vertebral fractures were diagnosed in 127 patients (54 %), of which 71 (56 %) were stabilized surgically. Forty-one patients (32 %) had vertebral fractures on two or more levels, whereof 12 cases had fractures on noncontiguous levels. In 110 patients (46 %) the initial MDCT did not reveal any spinal injury. Burst fracture (n=78, 38 %) was the most common fracture type and was most frequently seen in the thoracolumbar junction (n=39, 50 %), whereas in the cervical spine only 10% (n=8) of burst fractures occurred. One or more burst fractures were seen in 71 (56 %) of the 127 injured patients. Also compression fracture (n=52, 26 %) was most commonly seen in the thoracolumbar junction (n=20, 39 %), and least commonly in the cervical spine (n=1, 2 %). Posterior column fracture (n=52, 26 %) was most frequently found in the cervical spine (n=21, 40 %), and was least common in the thoracolumbar junction (n=2, 4 %). Other fractures (n=21, 10 %) included ten fracture dislocations (48 %), one extension teardrop fracture (5 %), one type II odontoid process fracture of C2 (5 %), one atlanto-occipital dissociation (5 %), one isolated anterior longitudinal ligament rupture (5 %), a fracture of a lateral mass of C1 in two patients (10 %) and three bamboo spine fractures (14 %) in two patients with ankylosing spondylitis. These other fractures occurred almost exclusively in the cervical spine (n=19, 91 %). The remaining other fractures were one Chance fracture (5 %) in Th11, and one sagittal split fracture (5 %) in L2. 19 (90 %) of the 21 other fractures were considered unstable. The mean falling height of patients who had jumped (6.2 m) was higher than in patients who had fallen accidentally (3.7 m), though fractures of the spine did not occur significantly more frequently. There was no obvious difference in fracture type or location between patients who had jumped or fallen. Due to the limited number of patients who had jumped, statistical verification of this data was not possible. The overall incidence of fractures in general increased with increasing falling height (P=0.0182), which is also true for burst fracture. In contrast, posterior column and other fractures decreased, while the amount of compression fractures remained nearly constant. The proportion of thoracic spine fractures also increased with increasing falling height. This tendency could not be observed in the thoracolumbar junction or lumbar spine. Cervical spine fracture incidence decreased with increasing falling height, spine fractures occurred more frequently on multiple levels. The ratio of spine fractures to normal findings seemed to be independent of height as well as age. Falling height was inversely proportional to age, and the incidence of spine fractures did not decrease with age (P=0.0328). The relative amount of posterior column fractures increased with age, while there was neither a correlation of burst and compression fractures nor of other fracture types or multiple level fractures with age. Also, age had no effect on fracture location, type, or on the amount of normal examinations.

Pelvic trauma (II)

A total of 629 injuries of the pelvis, fifth lumbar vertebra, or proximal femur occurred in 226 (16 %) of 1386 patients, with an average of 2.7 injuries per patient. Of these 629 injuries, 591 (94 %) were fractures and 38 (6 %) were diastatic fractures of the fibrous sacroiliac or symphysis joints. The most common fracture sites were the superior and the inferior ramus, followed by fractures of the sacrum. Sacroiliac joint diastatic fractures were more common than ruptures of the pubic symphysis. Pelvic radiography was able to detect 342 fractures in these 226 patients, averaging 1.51 fractures per patient for an overall sensitivity of 55 % when compared to MDCT as standard. In 24 (11 %) patients the pelvic radiography was false-negatively normal, and all fractures were demonstrated subsequently by MDCT. Sensitivity of pelvic radiography depended on the anatomical region of the injury, and was best in the anteroinferior parts of the pelvis (pubic symphysis and rami), as well as the proximal femur. Sensitivity was fair for injuries of the acetabulum and iliac bone, and poor in the posterior ring of the pelvis (sacroiliac joints and sacrum) and the lowest lumbar vertebra L5. In 624 (45 %) of the 1386 cases, radiographic images of the pelvis were of suboptimal quality, mostly due to poor positioning of the film cassette (n=471; 34 %) In 153 radiographs (11 %) there were superimposed emergency room (ER) equipment or backboard artifacts visible in critical areas of the image. Using MDCT, 141 (62 %) of patients were classified according to the Tile classification for pelvic injuries, which is not applicable to lumbar spine or proximal femur fractures. In pelvic radiography, the Tile classification could be employed in 133 cases (59 %). In 72 cases (59 %) MDCT and pelvic radiography demonstrated the same fracture type (A, B, or C) of pelvic injury, and in 17 (14 %) of the cases also the same subtype (A1-3, B1-3, or C1-3) (Fig. 3; Table 3). Pelvic radiography found the pelvis false negatively stable (normal or Type A) in 48 cases (40%) with MDCT demonstrating either rotational (Type B; n=36), or rotational and vertical (Type C; n=12) instability.

Incidence of Burst Fractures (III)

In 15 of 152 cases (10 %), burst fractures were multiple and eight (53 %) of these were on non-contiguous levels. Three major trauma mechanisms were identified: falling, traffic, and recreational accidents including sports. In the falling accidents group (falling height range 1-12 m, mean 4.4 m), 82 patients (67 male; 82 %) sustained a total of 91 burst fractures. With a mean age of 42 years, it was also the oldest group. Neurological deficit (mean 0.4) correlated positively with falling height (linear regression; $P<0.001$). Falling accidents had the highest incidence of fractures of the lumbar spine. Car accidents accounted for 65 % (n=30) of the traffic-related injuries, followed by motorcycle (n=7, 15 %), bicycle (n=3, 7 %), and pedestrian accidents (n=3, 7 %). In traffic accidents, the mean neurological deficit (0.3) was the lowest, while the amount of females (n=19, 41 %) was the highest of the three main accident groups. In falling accidents, 15 patients (18 %) and in recreational accidents six (30 %) were female. Burst fractures in the thoracic spine were more common in traffic accidents (28 %) than in falls (15 %) or recreational accidents (17 %). Recreational accidents were associated with lower age (mean age 30 years), and a higher incidence of cervical spine injuries (26 %), as well as a lower incidence of lumbar spine injuries (9 %) compared to the other groups, in which the mean age was 42 years in falls, and 38 years in traffic-related accidents. In all types of accidents, the TLJ was the most common site of injury with 48 % each. The mean age in the male (39 years) and female (38 years) patient groups was similar. Of 112 males, 12 (11 %) had multiple burst fractures, thereof five (42 %) on noncontiguous levels. Of 40 females, three (8 %) had multiple burst fractures, all of which were noncontiguous. Differences in the distribution of burst fractures over the spine between genders were not significant (Mann-Whitney rank sum test; $P=0.478$). In both genders, the incidence of burst fractures peaked at the CTJ, between Th5 and Th8, and at the TLJ. Males were twice as likely to have a burst fracture in the CS (10 %) than females (5 %). In males, the predominant cause of injury was a falling accident (61 %), followed by traffic accidents (23 %). In females, trauma was most commonly related to a traffic accident (48 %), followed by falling accidents (38 %). Recreational accidents occurred at similar rates (13 % for males and 15 % for females). The majority of men in this group acquired their injuries by diving headfirst into shallow water (n=5, 36 %) or motocross biking (n=3, 21 %), whereas all injuries in women were related to horseback riding (6; 100 %). Other recreational accidents were a parachuting accident, an ultra-light plane crash, a snowmobile accident, a bobsled accident, and a freestyle skiing accident. 106 patients had a neurological deficit of 0 (70 %), 22 had a neurological deficit of 1 (14 %), and 19 a neurological deficit of 2 (13 %). The percentage missing to 100 % comes from five patients whose neurological deficit immediately after trauma could not be reliably determined. The mean neurological deficit was highest in CS burst fractures (1.5) independent of trauma mechanism, and lowest in TLJ burst fractures (0.3). In recreational accidents, the mean neurological deficit (0.6) was twice as high as in any other group, and the incidence of CS injuries (26 %) the highest. The mean neurological deficit in TS burst fractures was more severe if acquired through a fall (0.8) than those sustained from traffic (0.0), recreational (0.0), and other accidents (0.5).

Burst fractures measurements (IV)

108 patients with one or more burst fractures who had undergone diagnostic MDCT as well as radiography in the acute phase had 121 burst fractures. Eleven patients had multiple burst fractures, of which 7 (64 %) were noncontiguous. Thirteen fractures (11 %) were cervical, 25 (21 %) thoracic, 55 (45 %) at the thoracolumbar junction, and 28 (23 %) lumbar. In burst fractures of the cervical spine, 70 % of patients had grade 2 neurological symptoms, with only 20 % Grade 0 findings. In the other spinal regions few patients showed Grade 2 neurological deficit, which further decreased with decreasing spinal levels (10 % TS; 5 % TLJ; 0 % LS), as compared to high numbers of patients with grade 0 neurological symptoms (85 % TS; 80 % TLJ; 70 % LS). Grade 1 neurological deficit was more common in the lower parts of the spine (5 % TS; 13 % TLJ; 26 % LS). Measurements from radiographs tended on average to underestimate spinal canal narrowing and interpedicular widening compared to MDCT, and to overestimate vertebral compression. The mean absolute difference varied between 0.2 and 2.5 mm, depending on type of measurement and vertebral region. MDCT and radiographic measurements showed a strong positive correlation with a mean correlation coefficient of 0.67, with the highest correlation (k=0.91; $P<0.001$) in interpedicular widening in the LS, and the lowest but still significant correlation at the 0.05 level (k=0.5; $P=0.029$) in spinal canal narrowing in the TS. No significant correlations of any measurements

could be established in the CS. All other measurements correlated significantly at the 99 % confidence level between MDCT and radiography.

Sports and recreational accidents (V)

Three of 492 patients presented twice during this study because of similar but unrelated sports accidents. The overall number of MDCT examinations of the head, spine, and torso performed in this population was 799 (324 head, 306 cervical spine, 11 thoracic spine, 26 lumbar spine, 55 whole body, and 77 facial bones). In 9 cases, an additional MRI was used to exclude injury, of which one provided significant additional information. All of these additional MRIs were of the CS. In 110 cases, radiography was performed before MDCT, usually in peripheral hospitals to which the patients had been admitted primarily, and from whence they were immediately referred to Töölö hospital. The most common accident mechanism was bicycling (n=151; 31 %), followed by horseback riding accidents (n=71; 14 %), team ball sports (n=49; 10 %), ice hockey (n=44; 9 %), and skiing/snowboarding (n=28; 6 %). The complete list of trauma mechanisms and injuries is presented in Table 4.

A total of 102 traumatic findings were diagnosed: 58 craniofacial, 15 in the cervical spine, 6 in the thoracic spine, 11 in the lumbar spine, and 12 in different other areas of the torso. Of these, 72 were classified as serious injuries: 46 craniofacial, 8 in the cervical spine, 3 in the thoracic spine, 7 in the lumbar spine, and 6 in different areas of the torso, which averages to 14.6 %, or 5.9 normal examinations per serious injury. Serious injuries were defined as requiring invasive treatment or hospitalization. Overall, bicycle accidents produced the highest number of positive findings and serious injuries with n=45 and n=36, respectively, which amounts to a ratio of 2.4 normal cases for every injury and 3.2 for every serious injury, or 29.8 % and 23.8 %, respectively. The ratios of normal cases to injuries and serious injuries in the other most common accident mechanisms were 5.5 and 7.9 (n=11 and 8; 15.7 % and 11.4 %) in horseback riding, 10 and 13.7 (n=4 and 3; 14.3 % and 6.1 %) in ice hockey. Also, some smaller groups such as boating accidents produced high ratios of injury to normal findings, which nevertheless cannot be considered representative due to small sample size. Participants in high-energy sports and other physically demanding activities were on average younger (mean age 29.2 years) than their counterparts in less strenuous activities (mean age 36.9 years; t-test for unpaired data; $P<0.001$). Data on examinations, total injuries, serious injuries, case numbers, and age is presented in Table 4 by accident mechanism. These groups differed significantly in their mean age (one-way ANOVA; $P<0.001$) as well as in injury severity (Kruskal-Wallis test; $P=0.026$). The t-test for unpaired data (CI 95 %) showed a significant difference in mean age in bicycle ($P<0.001$), team ball sports ($P=0.001$), ice hockey ($P<0.0001$), motorized land sports ($P=0.0014$), and gymnastics ($P=0.003$). Wilcoxon rank sum test (CI 95 %) revealed that injury severity was significantly different only in the bicycle group ($P<0.001$). The three most commonly encountered serious injuries were intracranial injury (including contusion, hemorrhage, skull and skull base fractures; n=33), facial bones (including fractures of the upper and lower jaw, zygomatic bone, orbits and complex fractures; n=28), and vertebral injuries (including stable and unstable fractures, and dislocations of vertebral body and posterior arc; n=26). Craniofacial injuries were especially common in bicycle accidents. Most common in other injuries were traumatic pneumothorax associated with rib fractures (n=5), and rib fractures without pneumothorax (n=4). Neither tension pneumothorax nor flail-chest was seen.

Cases were normally distributed over the age groups with a peak in the group from 21 to 30 years. All age groups included more men than women. Relative risk for injury seems to increase with age, with a trough in the age group 51 to 60. The relative risk for injuries requiring treatment peaks in the age group 21 to 30 and seems to rise again after age 50.Kruskal-Wallis test reveals a statistically significant difference of injury severity between age groups ($P=0.018$; CI 95 %), while further investigation by Wilcoxon rank sum test (CI 95 %) shows a significant difference in injury severity for patients younger than 21 ($P=0.004$) and between 41 and 50 ($P=0.031$).

Table 4 Case numbers, imaging modalities, injuries, and serious injuries by trauma mechanism.

	Cases (n)	Craniofacial total/ inj/sinj	CS total/inj/sinj	TS total/inj/sinj	LS total/inj/sinj	Torso total/inj/sinj	All MDCT total/inj/sinj	Normal cases per injury	Normal cases per serious injury	Mean age (years)
Bicycle	151	164/35/29	100/4/2	4/2/1	2/2/2	13/2/2	283/45/36	2.4	3.2	38.7
Horseback Riding	71	45/2/2	49/2/1	1/1/1	5/2/2	13/4/2	113/11/8	5.5	7.9	33.2
Ice hockey	44	34/2/1	27/1/1	1/1/1	3/0/0	2/0/0	67/4/3	10	13.7	23.9
Skiing	28	18/2/2	13/1/0	0/0/0	6/2/1	3/1/0	40/6/3	3.7	8.3	32.5
Soccer	26	22/1/1	10/1/0	3/1/0	0	0	34/3/1	7.7	25	25.5
Swimming	21	9/0/0	19/2/2	0	1/1/0	2/0/0	31/3/2	6	9.5	30.8
Motocross	18	12/0/0	15/1/0	0	1/0/0	11/3/0	39/4/0	3.5	-	23.1
Other motorized land sports	15	8/2/1	11/0/0	1/0/0	0	6/0/0	26/2/1	6.5	14	31.1
Martial arts	13	7/1/1	10/1/0	0	0	0	17/2/1	5.5	12	29.8
Gymnastics	12	7/2/1	10/1/1	0	0	0	17/3/2	3	5	21
Other team ball games	12	8/2/1	5/0/0	0	1/0/0	0	14/2/1	5	11	21.7
Floorball	11	8/1/1	5/0/0	0	1/1/0	0	14/2/1	4.5	10	34
Ice skating	9	9/0/0	3/0/0	0	0	0	12/0/0	-	-	39.7
Sled racing	8	7/0/0	5/0/0	0	1/1/1	1/0/0	14/1/1	7	7	28
Gym / fitness	8	5/0/0	3/0/0	0	0	0	8/0/0	-	-	30.3
Roller skates / skateboard	6	4/1/1	1/1/1	1/1/1	1/0/0	0	7/3/3	1	1	38
Boating / sailing	6	6/3/3	3/0/0	0	1/1/1	0	10/4/4	0.5	0.5	32.8
Sauna	6	5/0/0	2/0/0	0	1/0/0	0	8/0/0	-	-	40.5
Reckless stunts	5	5/2/0	1/0/0	0	0	0	6/2/0	1.5	-	25.4
Dancing	4	5/1/1	2/0/0	0	0	0	7/1/1	3	3	27.8

Track & field	3	1/0/0	2/0/0	0	0	0	3/0/0	-	-	33
Climbing	2	2/0/0	2/0/0	0	0	0	4/0/0	-	-	14
Golf	2	1/0/0	1/0/0	0	0	0	2/0/0	-	-	45
Curling	2	1/0/0	1/0/0	0	0	1/1/1	3/1/1	1	1	43.5
Tennis	2	2/0/0	1/0/0	0	0	0	3/0/0	-	-	38.5
Hammock	2	1/0/0	2/0/0	0	0	0	3/0/0	-	-	45.5
Croquet	1	1/0/0	0	0	0	0	1/0/0	-	-	29
Ultralight plane crash	1	1/0/0	1/0/0	0	0	1/0/0	3/0/0	-	-	34
Parachuting	1	0	0	0	0	1/0/0	1/0/0	-	-	30
Jet ski	1	2/1/1	1/0/0	0	0	0	3/1/1	0	0	45
Wakeboard	1	1/0/0	0	0	0	0	1/0/0	-	-	31
Wood chopping	1	0	0	0	1/1/1	0	1/1/1	0	0	45
Amusement park	1	1/0/0	0	0	0	0	1/0/0	-	-	22
Playground	1	1/0/0	1/0/0	0	0	1/1/1	3/1/1	0	0	12
Total	495	401/58/46	306/15/8	11/6/3	26/11/7	55/12/6	799/102/72	3.9	5.9	33.5

CS cervical spine; *TS* thoracic spine; *LS* lumbar spine; *inj* injuries; *sinj* serious injuries.

DISCUSSION

General

Because of its high availability, high diagnostic accuracy, time- and cost-effectiveness as well as its lack of absolute contraindications, MDCT is the reference standard for primary trauma evaluation in a stable patient (Prolok 2003, Harris 2000). MDCT is fast, limits motion artifacts and reduces partial volume effects, creates less image noise, has better opacification of blood vessels after intravenous contrast administration, and increased enhancement of parenchymal organs, high-quality multiplanar reformation (MPR) due to isotropic voxels, which makes it superior to single-detector CT as well as CR. All these properties increase the value of MDCT in a trauma setting, which translates to improved outcome for the patient (Novelline et al. 1999, Linsenmayer et al. 2002, Rydberg et al. 2000, Harris 2000, Prolok 2003). Reformats in the sagittal plane have been considered standard in spine CT for quite some time (Novelline et al 1999), and they are also routinely included in our institution. 3D surface renderings contribute to fracture classification and show the spatial relation of fragments in an easily comprehensible format, which is instrumental in the planning of surgery (Kösling et al. 1997, Geijer 2006). 2D and 3D reformatted images of the helical MDCT data set are usually excellent in any plane and quickly done, improving not only diagnosis by the radiologist, but also the planning process of invasive procedures by the trauma surgeon (Kösling et al. 1997, Geijer 2006). CR still plays a role in the evaluation of unstable patients, as does FAST ultrasound. Nevertheless, neither imaging modality provides the broad overview and accuracy of MDCT.

Although MDCT systems with at this time up to 320-slice MDCT scanners (Aquillion ONE 320, Toshiba Medical, Tokyo, Japan) speed up the imaging process and decrease artifacts, total acquisition time per patient is unlikely to decrease significantly in the near future, as the actual scanning time takes up only a minor part of the occupied scanner room time. The greater part of the occupied scanner room time is spent with patient preparation, injector setup, and the programming of the scanner. This is especially the case in seriously injured trauma patients, whose vital signs are continuously being monitored by emergency room staff and, if necessary, life saving therapies are administered while the patient is in the CT scanner room.

MRI is quickly becoming a standard commodity even in smaller hospitals, but will probably not be a routine means of examination in primary trauma evaluation in the near future, mainly due to time- and place-restrictions as well as numerous absolute and relative contraindications. The MDCT protocols used in this study (Table 1) represent the values adapted for the specific scanners and requirements in Töölö hospital, and are under constant scrutiny by physicists and radiologists to improve results. Our institution’s routine protocol for cerebral trauma MDCT will be supplemented in the near future with routine CT angiography to exclude cerebrovascular injuries such as traumatic aneurysm, which is a frequently under-diagnosed injury (Nakstad et al. 2008). Limitations of this study are the retrospective study design of its parts, and that it is limited to only one level one trauma center in one geographic region. Additionally, some of the subgroups are so small that statistic analysis cannot be performed, which was addressed by using comprehensive classifications with relatively few subgroups. Due to the random nature of the findings, this effect could nevertheless not be altogether avoided.

Falling accidents (I)

Severe falling accidents are relatively common. During the 26-month-period covered by this study, a total of 237 patients were admitted after falling accidents, averaging one falling accident every third day. Because of the possible high trauma energy, standard trauma imaging protocol applies, which consists of whole-body MDCT including MDCT of the cervical spine and head. The radiation dose the patient is exposed to is considered acceptable compared to the possible consequences of a missed spinal injury (Jelly et al. 2000). Because Töölö hospital is the only level one trauma center in the capital region of Helsinki and Uusimaa with a population of about 1.4 million, the data in this study should provide a reliable and representative picture of adult spine fractures in falling accidents.

The most common vertebral fracture was the burst fracture, located most frequently in the thoracolumbar junction. This is in agreement with previous studies (Denis 1984, Harris 2000, Mohanty 2002). Stable compression and posterior column fractures were less common than unstable burst fractures. Compression and burst fractures occurred mainly at the thoracolumbar junction. Since radiography cannot reliably distinguish compression from burst fracture, MDCT should be used to differentiate these two fracture types, as stability is the main parameter for treatment decision as well as for the patient's prognosis.

In the present study, the incidence of burst and compression fractures increased with falling height, which is in accordance with experimental results (Wilcox 2002 and 2003). From lower heights the patients probably hit the ground headfirst, resulting in hyperflexion or -extension injury due to the high mobility of the cervical spine (Daffner 2002), whereas falling from greater heights allows for rearrangement of the body resulting in a feet first-impact and therefore axial load on the spine, additional to the higher energy from falling height. This might explain the increase of burst and compression fracture incidence with height. Posterior column fractures are mostly hyperflexion injuries (Allen 1982) and therefore most common in the very mobile cervical spine. In our study, the proportion of CS fractures decreased with height, probably due to the fact that increasing falling height results in more severe head and neck injuries if a subject hits the ground headfirst, causing a higher pre-hospitalization mortality. Another reason could be the aforementioned probable realignment of the body during the fall. This might explain why there were less upper cervical spine injuries in our study than in the NEXUS cervical spine injury cohort (Goldberg et al. 2001). The amount of suicide attempts among the group who had fallen remains unknown, since a patient cannot be expected to readily reveal the exact circumstances of the injury under these circumstances.

Falling height was inversely proportional to age, which does not seem to affect the incidence of fractures of the spine. This might be because of a more brittle and weakened bone structure with decreased elasticity in older patients, resulting in decreased capacity to absorb and withstand impact forces. This makes a fracture more likely regardless of falling height (Mann 2002).

The ratio of MDCT examinations with pathological findings to those without pathological findings was about constant regardless of falling height or age. Only the amount of normal cervical MDCT examinations increased with falling height, most likely for the aforementioned reasons.

Multiple level spine fractures were seen in 41 (32 %) patients, of which in 12 patients (29 %) the fractures were at noncontiguous levels, which is in accordance with previous publications (Keenen et al. 1990). Radiographs are not reliable in the diagnosis of these cases. But also if the field of view of an MDCT examination is too limited, these fractures remain easily undiagnosed. Routine sagittal and coronal reformats help avoiding this pitfall. Lateral cervical radiography is obsolete and no longer included in the trauma series of seriously traumatized patients (Novelline et al. 1999, Nunez et al. 1994).

Pelvic trauma (II)

Pelvic injuries in level I trauma centers are associated with high morbidity and mortality, and occur mostly in early adulthood in conjunction with high-energy trauma (Dalinka 1985). Frequently, the definite pelvic ring or acetabulum fracture treatment consists of surgical stabilization (Gillot et al. 1988, Davidson et al. 1993, Pohlemann et al. 1994, Duane et al. 2001). Concomitant soft tissue injury associated with a pelvic injury has the potential to complicate further treatment considerably, and may itself be a cause of death (Kataoka et al. 2009). Pelvic CR is routinely included in the initial trauma series in many trauma centers, and is furthermore recommended by the American College of Surgeons (ACS 1997) for polytrauma patients. Positioning of a portable x-ray system close to the patient and the placement of the film is time consuming and interferes with the initial clinical examination. One main reason for the suboptimal sensitivity of pelvic radiography is poor positioning of the patient or the film cassette. During imaging, all emergency room staff must leave the area of exposure, which interrupts the flow of primary diagnostics and treatment. Use of protective gowning and aprons might enable the emergency room staff to stay close to the patient during exposure, but has the disadvantage of being cumbersome, and might possibly compromise the staff's performance, and furthermore still expose them to an unnecessary amount of radiation.

MDCT depicts the exact fracture morphology considerably better compared to pelvic radiography. The overall sensitivity of pelvic radiography is only moderate, confirming previously published results (Stewart et al. 2002, Vo et al. 2004). Due to its poor sensitivity especially in the posterior ring, pelvic radiography cannot reliably rule out an unstable injury, which might possibly lead to an inappropriate choice of treatment.

CT is commonly performed to screen seriously injured patients (Leidner 2001) and reveals soft tissue injuries such as occult hematoma, which results mainly from arterial hemorrhage and often requires angiography and embolization of hemorrhaging vessels. In addition to faster acquisition times and better temporal, spatial, and contrast resolution compared to conventional helical CT, MDCT also provides MPR and 3D surface renderings (Pokrop 2003, Linsenmayer et al. 2002, Rydberg et al. 2000), which are especially helpful in areas of complex, three-dimensional anatomy such as the pelvis. For these reasons, MDCT has become the imaging technique of choice in the evaluation of high-energy pelvic injury. MPR are helpful in disclosing fracture patterns and spatial relation of fragments, particularly in complex pelvic and acetabulum injuries, but in our opinion they are not as essential as for example in joint fractures, where they are routinely performed (Haapamäki et al. 2004).

Pelvic radiography has a role in the initial trauma series if a patient is hemodynamically unstable or unconscious. If conventional pelvic radiography reveals an unstable and dislocated injury of the pelvic ring, and major hemorrhage is suspected or confirmed by FAST, external stabilization of the pelvic ring and/or angiography and embolization may be required before CT can be safely performed. Due to its low sensitivity, conventional pelvic radiography has a very limited value in assessing the exact fracture pattern, and is furthermore not reliable in determining fracture stability. In the initial trauma series, conventional pelvic radiography is time consuming and interrupts primary treatment and diagnosis. Routine use of pelvic radiography represents therefore inappropriate use of resources and avoidable radiation exposure when assessing hemodynamically stable patients, but is preferable to CT when the patient is hemodynamically unstable.

Burst fractures incidence (III)

Burst fracture is the most common type of thoracolumbar injury associated with high-energy trauma (Dai et al. 2008). Falling, traffic, and sports or recreational accidents account for most of the injuries (Trivedi et al. 2002, Floyd 2001, Kiuru et al. 2002, Wilcox et al. 2003, Atlas et al. 1986, et al. 2002, Wintermark et al. 2003). Due to the considerable forces acting on the vertebrae, burst fractures occur commonly on multiple levels, and often non-contiguously (Cassar-Pullicino 2002, Denis 1984). These findings are in accordance with this study, where 10 % of vertebral burst fractures occurred on more than one vertebral level and more than half of these non-contiguously. During the time interval of this part of the study, burst fracture was diagnosed almost once per week on average. This relatively high incidence, combined with the inherently unstable nature of this fracture type and its therefore potentially disastrous consequences demand a high level of suspicion for burst fracture in all high-energy traumatized patients (Meves et al. 2005, Bohlman 1985).

An explanation for the low mean neurological deficit encountered in this study could be the relatively high incidence of lumbar fractures, because the ratio of neural tissue to the amount of cerebrospinal fluid in the spinal canal decreases on lower levels, which provides more space for these tissues to evade compression or transsection. This makes neural damage far less likely in the LS than on higher spinal levels. Neurological deficit correlates with falling height, as a longer fall usually results in higher deceleration energy on impact, with increased tissue deformation as a result (Wilcox et al. 2003, Mohanty et al. 2002). The higher incidence of neurological deficit in the CS is in accord with previous publications, showing increasing severity of the neurological deficit with increasing height of the lesion (Jelly et al. 2000, Meves et al. 2005, Saifuddin et al. 1996, Dai 2001, Rydberg et al. 2000). The lowest mean neurological deficit was found in the TLJ, where it is just slightly lower than in the TS and LS. TS burst fractures' lower neurological deficit may be explained by the additional stability the rib cage provides. Burst fractures of the thoracic spine produced very low mean neurological deficits in all but the falling accidents group, which could be due to a higher trauma energy in falling injuries, but probably reflects a higher probability of direct axial load due to the aforementioned presumed tendency to realign the body during the fall.

In traffic accidents, MVAs were the most common trauma mechanism. TS burst fractures were especially common in this group. Additionally, it had the lowest mean neurological deficit. Flexion components might contribute to that as well as factors such as fixation of body parts by seat belts. Also other protective measures such as airbags and overall impact force-absorbing automobile chassis architecture might play a role. Furthermore, the MVA group had the highest rate of female patients, which is probably due to traffic being a normal part of everyday life for men as well as women, whereas in the other groups, the risk is taken more voluntarily, which men are generally still more likely to do (e.g. extreme sports, working at great heights). Similarly, sports accidents had the lowest mean age, which reflects the fact that young people engage more likely in venturesome activities (Meves et al. 2005, Hostetler 2004, Wang 2009). The high mean neurological deficit in such injuries stems from the highest incidence of CS and the lowest incidence of LS fractures in this group, which makes neural damage more likely for the reasons mentioned above. Burst fractures occurred at very similar rates in both genders, as the spinal anatomy is similar and differences in bone density are likely minimal in the predominant age groups. It is noteworthy, though, that most men in this group acquired their injury due to reckless behaviour, such as diving headfirst into shallow water, or motocross jumps. Horseback riding, the major cause of fractures in female sports accidents in this study, has been reported previously as a serious risk for injury affecting a predominantly female population (Kiuru et al. 2002, Fontijne et al. 1992). The fact that for all female patients in the sports accidents group the accident mechanism was horseback riding reflects most likely just an overrepresentation due to small sample size. The dominant role of horseback riding in serious sport injuries of women is nevertheless undeniable. Burst fracture occurred commonly at the CTJ, at TS levels Th5 to Th8, and most frequently at the TLJ. These locations represent the most mobile (CTJ, TLJ) as well as the most rigid (TS) sections of the spine. For the TLJ, this has been well documented (Starr et al. 1992, Meves et al. 2005, Bohlman 1985, Atlas et al. 1986, Saifuddin 1996).

The distribution of burst fractures over the spine showed no statistically significant difference between genders, but the mean neurological deficit was significantly higher in males. Genders also differed depending on the accident type. For males, the most common cause of injury was falls followed by traffic accidents, whereas for females the opposite was true. Both accident types are frequently high-energy traumas and are very often associated with burst fractures (Trivedi et al. 2002, Meves et al. 2005, Leferink et al. 2003, Harris 2000).

Burst fracture measurements (IV)

As shown before, burst fractures of the spine are common in high-energy accidents such as traffic accidents, falls from a height, and in sports accidents, and may have serious and possibly permanent consequences (Meves et al. 2006, Daffner et al. 2002, Trivedi et al. 2002, Floyd 2001, Wilcox et al. 2002, Berlin 2003, Kiuru et al. 2002), even though the long-term outcome is still mostly favorable (Moller et al. 2006, Shen 2001). Multiple fractures can be non-contiguous and pose therefore a diagnostic challenge (Cassar-Pullicino 2002, Dai 2001). The optimal choice of imaging modality is crucial for the correct diagnosis. In places where CT is not yet readily available, two-view conventional radiography, supplemented with oblique views, if necessary, is still considered the minimum requirement for exclusion of spinal injury. In postoperative follow up, radiography is being widely used because of time and budget restraints, but most of all because of the smaller radiation dose. The diagnostic value of radiography is, however, often limited by superimposed soft tissue, bones, or bowel gas, technical equipment or other foreign objects visible in the picture, or by the inferior image quality of mobile radiography units especially in the primary phase. Additionally, multiple views are often unattainable and may be even hazardous for polytrauma patients due to the risk of secondary injury during repositioning.

The traditional way to diagnose a burst fracture of the spinal column on radiography is by demonstrating compression of the anterior spinal column and disruption of the middle spinal column, with the retropulsed bone fragment obstructing the spinal canal on lateral views. However, in some cases these signs are equivocal. By measuring interpedicular widening in the AP projection and comparing it to the mean of measurements of the vertebrae above and below the fracture, disruption of the middle column of the vertebra can be readily detected by a sufficiently experienced radiologist (Daffner et al. 2002, Saifuddin et al. 1996). An increase in interpedicular distance of more than 2 mm relative to the mean of the measurements from the adjoining vertebrae is considered pathologic (Daffner et al. 2002). A disrupted middle column is highly suggestive of a burst fracture (Daffner et al. 2002).

With MDCT as standard, the accuracy of measurements from radiographs was generally good. Measurements of spinal canal narrowing in particular, being arguably the most crucial, were highly accurate: The mean difference from the standard was only 0.9 mm. These findings suggest that burst fractures can be assessed with acceptable accuracy from radiographs alone, provided the radiologist has sufficient experience, and that the images are of adequate diagnostic quality. Radiography is especially suitable for post-operative follow-up imaging, where morphology and the exact level of the fracture(s) has already been established, and if there is no clinical suspicion for additional injuries acquired after primary diagnosis.

Measurements from radiography and MDCT showed a strong correlation, which was mostly statistically significant. As an exception, TS spinal canal narrowing did not correlate well, and correlation of measurements of TS interpedicular widening was not significant. This might reflect that the superimposed rib cage and soft tissues may hamper the assessment of these intricate vertebral structures. This is in accord with a previous study, which found the diagnostic value of radiography in the TS to be unsatisfactory. Hauser et al. reported only 58 % sensitivity for fractures in radiography, compared to 97 % in CT (Hauser et al. 2003). A missed injury in this region is less likely to cause permanent damage, since the rib cage as a relatively rigid, rotationally stable structure provides additional stability. This is also reflected by the lowest observed incidence of neurological deficit being in the TS. Radiologists and clinicians alike should nevertheless be aware of this blind spot in thoracic spine radiography. Nevertheless spinal injury should be excluded by MDCT, as mentioned before. The spinal levels best visualized on radiography due to least summation of structures such as the lumbar vertebrae had the highest degree of correlation with CT as could be expected. Vertebral compression is, however, hard to correlate since lateral view radiographs superimpose the entire, slightly cup-shaped vertebral endplate. Therefore, correlation with CT is relatively low, but differs only by a few millimeters on average. Vertebral compression is not specific for an unstable injury in the primary diagnostic workup of burst fractures, and the parameter is therefore secondary to highly specific changes such as interpedicular widening. In postoperative follow-up by radiography, a difference of a few millimeters in vertebral body compression may be the result of inherent geometric distortion or projection differences, and does not necessarily indicate instability. Therefore, the percentage of compression compared to the mean of the vertebrae directly above and below probably gives a better estimate of the actual damage.

Interpedicular widening strongly indicates vertebral burst fracture (Daffner et al. 2002) and correlated very well except for the CS and TS areas. As observed before, this suggests that radiography alone is sufficient for the diagnosis of thoracolumbar junction and lumbar burst fractures, if image quality is adequate and the interpreting physician sufficiently experienced. If whole-body CT is being performed routinely, the additional radiation dose from cervical spine CT instead of two- or four-view radiography is negligible, while it saves valuable time on the acquisition as well as the interpretation side, and does not require repositioning of the patient. Thoracic and lumbar spine images can be reformatted from the helical body MDCT data set. Whereas a radiograph's sensitivity relies highly on the viewers' experience, CT depicts fracture morphology unambiguously, which is especially beneficial in an emergency setting when accurate and prompt diagnosis is expected also from inexperienced radiologists and/or trauma surgeons. Accurate evaluation of spinal canal compromise is not always possible on radiography, but since the final resting position of the retropulsed bone fragments correlates poorly with retropulsion during the impact (Wilcox et al. 2002), it is primarily important to detect involvement of the middle column indicating an unstable fracture, even in the absence of neurological symptoms.

Sports and recreational accidents (V)

The majority of MDCT examinations in this study revealed no radiologically detectable signs of injury independent of trauma mechanism and age. Injuries were nevertheless likely to be serious, especially in the craniofacial area and the CS. Since these areas have a high potential for severe injury or injury progression, exclusion of suspected injuries by MDCT is imperative. In this rather young patient population, the cumulative costs of a missed and therefore primarily un- or mistreated severe injury for treatment, rehabilitation, and loss of productivity outweigh the costs of any retrospectively unnecessary MDCT examinations by far. Radiation dose has steadily decreased in recent years without loss of diagnostic power, due to the minimization efforts of manufacturers and hospitals through better soft- and hardware as well as refined examination protocols. Additionally, one should keep in mind that exposure to radiation in the diagnostic range usually stays well below the threshold of deterministic effects, causing instead stochastic (or random) effects without a linear causal relation between dose and incidence of related pathology.

If viewed by accident mechanism, high energy and team sports have a significantly lower mean participant age than less strenuous spare time activities, which might reflect the lifestyle choices of younger demographics. Gender distribution showed a strong female dominance in horseback riding, while in team sports and motorized activities women were clearly underrepresented, suggesting gender-specific risk groups. Widely popular activities like bicycling, skiing and swimming produced a high number of injuries, while higher energy accident mechanisms such as motorized sports, or very physical team sports such as ice hockey produced relatively few injuries. This can be explained by highly trained and specialized individuals in the latter groups, who are more likely to or even required to wear protective gear, and who will be fully concentrated on and mostly experienced in their sport. The former, on the other hand, are more likely to engage in their activities in a leisurely manner, probably experiencing distraction and not wearing any protective gear. High incidences of injuries and serious injuries in some of the smaller subgroups are based on small sample size, and do not necessarily reflect the true risk associated with these activities.

Overall incidence of injury and serious injury both increase with age, the reason for which may be slower reaction times, more brittle bones and blood vessels, and deteriorating overall health. The apparent peak of serious injuries at age 21 to 30 is according to our results within the limits of statistical variation, while patients of less than 21 years of age are more likely to have a serious injury. An increased incidence of trauma in these age groups may result from the patients' being in their prime, and being more likely to participate in high-energy sports and activities, leading to higher trauma energies. Recklessness may contribute to this. Women are fewer in all age groups, which could be due to their being more careful or more dexterous, but reflects most likely lower participation rates in these activities. One limitation of this study is the geographically specific mix of sports and recreational activities, which reflects Nordic customs and might be very different in other parts of the world, which could in turn affect the frequency with which certain trauma mechanisms present. Nevertheless, even though for example ice hockey might not be a mass sport in warmer regions, there will likely be an equivalent contact sport involving high velocities and high-energy impacts, such as for example Australian rugby.

CONCLUSIONS

Falling accidents (I*)*

Spine fractures due to falling accidents are common. Burst fracture is the most common fracture type and most frequently seen in the thoracolumbar junction. Multiple level fractures occur in about one third of cases, and frequently on noncontiguous levels, requiring the whole spine to be imaged. Serious spine fractures occur in all falling height, age, and gender groups.

Pelvic trauma (II)

Sensitivity of conventional pelvic radiography for correct fracture classification and detection is low, and does not allow for reliable evaluation of the stability of a pelvic fracture. Routine use of conventional pelvic radiography in the initial trauma series of hemodynamically stable patients consumes time and resources without any additional benefit for the patient. It is, however, recommended for the primary assessment of hemodynamically unstable patients when MDCT cannot be safely performed.

Incidence of burst fractures (III)

Vertebral burst fractures are frequently encountered in trauma patients of both genders and all age groups, and require thorough diagnostics, as they might cause irreversible damage, and should be considered unstable until proven otherwise to prevent secondary injury or injury progression. Neurological deficit is most common in conjunction with fractures of the CS independent of accident mechanism. Multiple burst fractures are seen in 10 % of cases, with half of them occurring on non-contiguous levels.

Burst fracture measurements (IV)

Radiography demonstrates interpedicular widening, spinal canal narrowing and vertebral compression in vertebral burst fractures with acceptable accuracy compared to MDCT, with the exception of the CS. MDCT is nevertheless recommended to avoid possible sources of error inherent to radiography.

Sports and recreational accidents (V)

Injuries of the craniofacial area, spine, and internal organs in sports and recreational accidents in all age groups and trauma mechanisms present with an overall incidence of 21 %, of which 71 % are serious. The three most common mechanisms of injury are bicycling, horseback riding, and team ball sports. The largest incidence of serious injury involved bicycling. Because of the high probability of an injury being serious, and the high energies that are often involved in these accidents, MDCT is recommended to rule out suspected injuries.

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