MULTIDETECTOR COMPUTED TOMOGRAPHY IN ACUTE JOINT FRACTURES

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ABSTRACT

Conventional radiography plays an essential diagnostic role in primary evaluation of acute joint trauma. In complex fractures, however, computed tomography (CT) is an imaging modality often used after radiography. Due to technical breakthroughs in the field, multidetector computed tomography (MDCT) allows faster imaging and better temporal, spatial, and contrast resolution compared with conventional single-slice spiral CT. The aim of this thesis was to assess the value of MDCT, compared with radiography, in the imaging of acute joint fractures in patients referred to a level-one trauma center.

All patients in the present study were imaged and treated on a clinical basis at Helsinki University Central Hospital, HUS Helsinki Medical Imaging Center, Töölö Hospital, Helsinki, Finland. MDCT and radiographic examinations were retrieved from digital archives and retrospectively analyzed, using a picture archiving and communications system (PACS). Patients with acute wrist, elbow, shoulder, or ankle and foot injury, and MDCT examination in the primary phase were included in the study. Primary radiographs of the injured joint were re-evaluated and then compared with the MDCT findings.

Radiography is suitable for use as the primary imaging modality in wrist trauma. MDCT can be used in equivocal cases to rule out fractures, detect occult fractures, and show the exact anatomy in wrist fractures, thus increasing diagnostic accuracy. In complex fracture patterns of the elbow and proximal humerus, MDCT is a complementary examination method that is often recommended when the extent of the fractures and the position or origin of dislocated fragments are not made clear by radiography. Multiplanar reformations (MPRs) in the coronal and sagittal planes show the joint anatomy without interference from superimposed structures and the origin of the fragment is

thus more easily revealed. The degree of dislocation in joint facets is better evaluated in MDCT with MPR than in radiographs. MDCT with MPR aids in surgical planning by increasing the accuracy of fracture classification in comminuted proximal humerus fractures. In complex fracture patterns of the ankle and foot and especially in high-energy multitrauma patients, the sensitivity of radiography is only moderate to poor. In these cases and in patients with equivocal radiographic images, MDCT scanning of the entire ankle and foot is recommended for use as the primary imaging modality. It can reveal occult Lisfranc fracture-dislocations and also other occult fractures in other parts of the ankle and foot. MDCT with MPR is helpful in disclosing fracture patterns, particularly in complex joint fractures where they reveal occult fractures and also show the exact number of fracture components and their degree of displacement.

LIST OF ORIGINAL PUBLICATIONS

This study is based on the following papers, which are referred to in the text by the Roman numerals I-V.

- I Kiuru MJ, Haapamäki VV, Koivikko MP, Koskinen SK
Wrist injuries: Diagnosis with multidetector CT
Emergency Radiology 2004;10:182-185

- II Haapamäki VV, Kiuru MJ, Koskinen SK
Multidetector CT diagnosis of adult elbow fractures
Acta Radiologica 2004;45:65-70

- III Haapamäki VV, Kiuru MJ, Koskinen SK
Multi-detector CT in shoulder fractures
Emergency Radiology, in press

- IV Haapamäki VV, Kiuru MJ, Koskinen SK
Foot and ankle injuries; Analysis of multidetector CT findings
American Journal of Roentgenology AJR 2004;183:615-622

- V Haapamäki VV, Kiuru MJ, Koskinen SK
Lisfranc fracture–dislocation; Diagnosis with multidetector CT
Foot and Ankle International, 2004;25:614-619

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ABBREVIATIONS

AP = Anteroposterior

CT = Computed tomography

FOV = Field of view

MDCT = Multidetector computed tomography

MPR = Multiplanar reformation

MRI = Magnetic resonance imaging

PA = Posteroanterior

PACS = Picture archiving and communication systems

p-y = Person-years

RI = Reconstruction increment

SCT = Spiral computed tomography

T1 = Longitudinal relaxation

T2 = Transverse relaxation

TE = Time to echo

TR = Repetition time

3-D = Three-dimensional

1. INTRODUCTION

Conventional radiography plays an essential diagnostic role in primary evaluation of bone and joint trauma. Usually the standard anteroposterior (AP) and lateral views are diagnostically adequate for assessment of trauma, but in more complex anatomic joint structures the superimposing bones make image interpretation challenging, especially in multiple and complicated fractures, and therefore additional views are needed.

Computed tomography (CT) is often used as a complementary imaging modality following radiography in complicated fractures. In level-one trauma centers, which are dedicated to the treatment of severe orthopedic and neurosurgical trauma, CT is routinely used for screening possible seriously injured patients (Leidner and Beckman 2001). Due to technical breakthroughs in the field, multidetector CT (MDCT) is faster and has better temporal, spatial, and contrast resolution compared with conventional single-slice spiral CT (Rydberg et al. 2000). Two-dimensional reformats (multiplanar reformation, MPR) and three-dimensional (3-D) surface renderings are also of better quality, and due to rapid image processing they can be done almost on-line. Therefore, MDCT has become the imaging method of choice in severe emergency trauma. In trauma hospitals where MDCT is readily available, it constitutes a one-stop shop in which severe injuries and fractures can be reliably diagnosed or ruled out. The purpose of the present study was to assess acute phase MDCT findings in joint fractures compared with radiography in patients referred to a level-one trauma center.

2. REVIEW OF THE LITERATURE

2.1 Fracture types and the incidence of joint trauma

Most trauma occur at the end of a bone (Rogers 1992) and joint injuries are among the commonest injuries treated in emergency departments. In males the highest rate of extremity fractures occurs in the second and third decades (up to 3000 per 100 000 person-years (p-y)); this decreases by 45 years of age to a relatively low rate that is maintained until 65 years of age, when it again increases. Women have relatively higher extremity fracture rates in the first 20 years of life (up to 1800 per 100 000 p-y), although the rate is appreciably lower than in males. The rate decreases in women and remains low until 45 years of age and increases considerably thereafter (over 3000 per 100 000 p-y at age 70) (Garraway et al. 1979).

2.1.1 Wrist

In adults, wrist injuries most commonly (90% of cases) involve the distal forearm, especially the distal radius and the most common injury mechanism is a fall on the outstretched hand (Cooney et al. 1991). The second most common fracture type of the upper extremity, after the distal forearm, is the scaphoid fracture accounting for approximately 2% of all upper extremity fractures (Brondum et al. 1992). Scaphoid fractures account for 75% of all carpal fractures, which are generally intraarticular (Bruser 1990). The classification and incidence of scaphoid fracture types by location of the fracture line is shown in Figure 1. Fractures of the capitate, lunate, and hamate bones account for only 1-3% of all carpal fractures (Bryan and Dobyns 1980, Cooney et al. 1991, Greenspan 2000). Fractures of the pisiform, triquetral, trapezium, and trapezoid bones are more rare. The most common dislocations in the wrist, ranging from least severe injury to the most severe, include the

scapholunate, perilunate, midcarpal, and lunate dislocations, which are associated with various degrees of interosseus ligament tears between the carpal bones (Greenspan 2000).

Two large population-based descriptive studies (Mallmin and Ljunghall 1992, Melton III et al. 1998) reported the annual overall incidence values for distal forearm (wrist) fractures: 287 per 100 000 p-y in 1985-1994 in Rochester, Minnesota, USA and 416 per 100 000 p-y in 1989-1990 in Uppsala, Sweden. There is a rapid rise in the incidence of forearm fractures with age in women up to about 10 years past menopause, with a slowing of the age-related increase thereafter (Hansson et al. 1982, Falch 1983, Miller and Evans 1985, Solgaard and Petersen 1985, Donaldson et al. 1990, Kanis and Pitt 1992, Melton III et al. 1998). The incidence of distal forearm fractures is much lower in men compared with women (Melton III 1995) and there is marked seasonal variation between different age-groups: in the elderly the peak fracture incidence occurs in the winter and in children (under 15 years of age) wrist and forearm fractures occur predominantly in the summer months (Wareham et al. 2003).

A

B

C

D

Fig. 1. Scaphoid tubercle (A) and distal pole (B) fractures account for 5-10% of all scaphoid fractures, 70-80% of fractures occur in the waist (C), and 15-20% in the proximal pole (D) (modified from Greenspan 2000).

2.1.2 Elbow

Elbow fractures most commonly involve the radial head in adults (Harris Jr 2000, Kandemir et al. 2002) and the injury mechanism is usually a fall onto the outstretched hand (Morrey et al. 1988). Radial head fractures were classified by Mason (1954) into 3 types: type I, undisplaced fractures; type II, marginal fractures with displacement (including impaction, depression, and angulation); and type III, comminuted fractures involving the entire head. In an urban population from Sweden, the incidence rates for adult radial head or neck fractures and for adult olecranon fractures were 2.9 per 10 000 (Herbertsson et al. 2004) and 1.15 per 10 000 individuals (Karlsson et al. 2002), respectively.

Based on the structure involved, fractures of the distal humerus can be classified as supracondylar (extraarticular), transcondylar, and intercondylar, as well as fractures of the medial and lateral epicondyles, capitellum, and trochlea. Robinson et al. (2003) reported an overall incidence rate of 5.7 per 100 000 p-y for adult distal humeral metaphyseal fractures in the elbow.

Anterior and posterolateral dislocations of both the radius and ulna in relation to the distal humerus are the most common types of elbow dislocation, accounting for 80-90% of all dislocations in the joint (Greenspan 2000). Isolated dislocation of the radial head is rare and is more commonly associated with fracture of the ulna (Monteggia fracture-dislocation).

2.1.3 Shoulder

Shoulder injuries are common and the injury types vary with age. In elderly patients the most common injury is humeral surgical neck fracture, which is often associated with avulsion fractures of the tubercles. Neer's (1970) classification of proximal humerus fractures based on the presence or absence of displacement of the 4 major fragments is shown in Figure 2. Proximal humeral fractures represent about 4% of all fractures seen in an average orthopedic clinic (Horak and Nilsson 1975). They commonly result from indirect injury such as a fall on the hand with the arm outstretched. Court-Brown et al. (2001) reported that the incidence of more complex proximal humeral fractures increases with age and the highest incidence of proximal humeral fractures (260 per 100 000 p-y) occurred in women between 80 and 89 years of age.

Glenohumeral joint dislocation is very common in younger adults and is the joint dislocation treated most often in the emergency department, with an overall incidence of 1.7% in the general population (Hovelius 1982, Kothari and Dronen 1992). Anterior dislocation is more common (approximately 97%) than posterior dislocation (2-3%) (Greenspan 2000). Pure inferior dislocation (luxatio erecta) is rare, accounting for 1-2% of shoulder dislocations (Rockwood and Ma 1996). In the extremely rare medial dislocation, the humeral head intrudes into the thorax due to direct trauma from the side. Injury to the rotator cuff of the shoulder may occur secondary to dislocation in the glenohumeral joint but is more commonly seen in patients over 50 years of age (Greenspan 2000). Typical fractures associated with shoulder dislocation include the posterolateral compression fracture (Hill-Sachs lesion), greater tuberosity fracture, and humeral neck fracture which are associated with 30-55% of anterior dislocations (Rowe 1980, Hendey and Kinlaw 1996, Rockwood and Ma 1996). The Hill-Sachs lesion may complicate up to 76% of all anterior shoulder dislocations (Perron et al. 2003). Approximately 15-35% of all glenohumeral dislocations have an associated

fracture of the greater tuberosity (Johnson and Bayley 1982, Hoelen et al. 1990, Slaa et al. 2001). The incidence of the bony Bankart lesion associated with anterior shoulder dislocation ranges from 5.4% to 32% (Bigliani et al. 1998, Slaa et al. 2001).

The glenoid cavity is affected in 10-30% of all scapular fractures (McGahan et al. 1980, Ideberg 1984, 1987, Ideberg et al. 1995). Scapular body fracture is caused by direct violence and scapular neck fracture is most often caused by a blow on the shoulder or by a fall on the outstretched arm. Coracoid process fracture may result from violent muscular contraction or, rarely, may be associated with anterior shoulder joint dislocation, or with acromioclavicular joint dislocation (Nordqvist and Petersson 1992). The fracture types of the scapula according to the anatomic location are shown in Figure 3. In 2 Swedish counties the annual incidence for scapular fractures was 10 per 100 000 p-y (Ideberg et al. 1995).

	2-part	3-part	4-part
Anatomical neck
Surgical neck
Greater tuberosity
Lesser tuberosity
Fracture-dislocation			
-anterior
-posterior

Fig. 2. Diagram of Neer's classification of proximal humerus fractures (modified from Hoffmeyer 2002).

Fig. 3. Scapular fractures classified according to the anatomic location:
(1) body, (2) glenoid rim or articular surface, (3) anatomic neck, (4) surgical neck,
(5) coracoid process, (6) acromion process, (7) spine (modified from Greenspan 2000).

2.1.4 Ankle and foot

The ankle is the most commonly injured joint in the body (Daly et al. 1987). The relative incidence of complex ankle and foot injuries has increased as a result of the increased use of automobile safety devices, such as seat belts and air bags, which decrease mortality and protect the trunk but not necessarily the lower extremities (Griend and Michelson 1996, Richter et al. 2001a). Ankle fractures are the most common types of fracture treated by orthopedic surgeons (Bauer et al. 1987). Ankle fractures can be subdivided into 2 categories: those that involve the malleolar projections (uni-, bi-, and trimalleolar fractures) and those involving the tibial plafond (pilon, Tillaux, and triplanar fractures) as shown in Figure 4. In Finland, the incidence of high-energy ankle fractures was 10 per 100 000 p-y and the incidence of low-energy ankle fractures was 150 per 100 000 p-y in a population over 60 years of age in 2000 (Kannus et al. 2002).

Foot fractures account for 10% of all fractures in the body (Rogers 1992) and they usually result from high-energy trauma, mainly due to a fall from a height or a motor vehicle accident (Sanders 2000). The most commonly fractured foot bone is the calcaneus, accounting for 60% of all foot fractures (Lowery and Calhoun 1996, Atkins 2001). Calcaneal fractures can be classified into 2 main categories: those sparing the subtalar joint (25%) and those extending into it (75%), the latter subdivided into joint-depression fractures and tongue-type fractures (Essex-Lopresti 1982). Talus fractures are the second most common fractures in the foot after calcaneus fractures, constitute 3-6% of all foot fractures (Adelaar 1989, Kuner et al. 1993), and can be divided into talar head, neck, body, and posterior process fractures. Injuries of the tarsometatarsal (Lisfranc) joint are relatively rare and are mostly related to high-energy trauma such as traffic, industrial, and falling accidents (Vuori and Aro 1993, Mantas and Burks 1994, Englanoff et al. 1995). The classification of Lisfranc fracture-dislocations is shown in Figure 5.

Fig. 4. Schematic pictures of fracture types involving the tibial plafond.
A, Pilon fracture. B, Tillaux fracture (avulsion fracture of the anterior tubercle of the tibia). C, Triplanar fracture (occurs in skeletally immature bone).
(modified from Rogers 1992).

Type A:
Total incongruity

Type B:
Partial incongruity

Type C:
Divergent

Fig. 5. Classification of tarsometatarsal (Lisfranc) fracture-dislocations (modified from DeLee JC. In Mann RA, Coughlin MJ: Surgery of the foot and ankle, ed 6, St Louis: Mosby 1993).

In general, ankle and foot dislocations are occasionally seen as a result of high-energy trauma but are less common than fractures of the ankle and foot. In most cases pure dislocations of the ankle are open (Garbuio et al. 1995). The majority of dislocations of the ankle joint are fracture-dislocations occurring in association with fractures of the malleoli and fibular shaft and tears of the collateral ligaments (Rogers 1992) and many are open fractures or fracture-dislocations due to high-energy direct trauma force. The most common dislocation in the foot occurs in the tarsometatarsal (Lisfranc) joint and the incidence of Lisfranc fracture-dislocations is approximately 1 per 55 000 p-y (Mantas and Burks 1994, Englanoff et al. 1995). Subtalar (peritalar) dislocation account for 1% of all dislocations in the foot (Pennal 1963).

2.2 Clinical diagnosis of acute joint trauma

Clinical examination of acute joint trauma includes careful history-taking and palpation of the painful region (Slätis 1980). Distal pulses and sensation are tested and skin changes and the ability to use the joint are recorded. Movements and stability of the joint are examined if marked swelling of the joint is not present. In case of joint swelling the primary diagnostic method is radiography. The general symptoms and signs of a joint injury are local pain, swelling, and restriction of motion. A hematoma can occur especially in a fracture. Visible or palpable joint deformity and bone tenderness or crepitation are typical findings in clinical examination of fractures and dislocations. In joint injuries the clinical findings vary according to the magnitude of injury, degree of displacement of fragments, and the interval since the injury. If the fragments are not displaced, examination soon after injury will demonstrate only slight tenderness and insignificant swelling.

Isolated severe sprain of the ligaments of the wrist joint is not common, and the diagnosis of wrist sprain should not be made until other lesions, such as carpal fractures and dislocations, have been ruled out. Scaphoid fracture is the most common injury to the carpus (Bruser 1990) and may be occult. If unrecognized it may lead to complications such as nonunion, osteonecrosis, and posttraumatic arthritis (Langhoff and Andersen 1988, Filan and Herbert 1995, Gaebler et al. 1996, Perron et al. 2001), and therefore identification of scaphoid fracture is important. It is difficult to differentiate carpal bone injuries by clinical examination and therefore it is imperative to obtain radiographs of the best possible quality. In the elbow region minor fracture deformities may not be apparent, because swelling usually obliterates palpable landmarks. Examination of peripheral nerve and vascular injury must be performed and all findings carefully recorded before treatment is instituted. Swelling of the shoulder region with visible or palpable deformity and restriction of motion due to pain are the principal clinical features in fractures involving the proximal humerus

and scapula. Pain and swelling are also prominent findings in fractures and dislocations of the ankle and foot region. Deformity may or may not be present. Clinical examination of the ankle and foot includes palpation of the painful region and joints proximal and distal to the area of injury. Bone tenderness and inability to bear weight are highly suggestive of fracture and radiography is thus indicated.

Clinical diagnosis may be difficult and is not reliable in ruling out or diagnosing fractures, therefore imaging methods must be used in the diagnosis. Conventional radiography has been and still is the primary imaging modality used in joint injuries.

2.3 Diagnostic imaging of acute joint trauma

2.3.1 Radiography

2.3.1.1 Technique

Radiography plays an essential role in the diagnosis of fractures, having been used as the primary imaging modality for more than 100 years. In comparison to analogous conventional radiography, recently introduced digital radiographic techniques offer advantages for optimization of image quality and dose. Currently, digital luminescence radiography (storage phosphor radiography) is the most commonly used digital method for obtaining images as a substitute for analogous conventional radiographs, using the established positioning projections and routines of the film-screen technique. The conventional film-screen cassette is replaced with a reusable storage phosphor-imaging plate that captures the incoming x-rays as a latent image. The inferior spatial resolution of digital luminescence radiography compared with that of the conventional film-screen system is compensated for by its superior contrast resolution, and its quality is adequate for diagnosing traumatic changes in all parts of the skeleton in daily routine (Bohndorf and Kilcoyne 2002). The technical spatial resolution of storage phosphor digital radiography is between 0.1 and 0.2 mm (Buckley et al 1991), but in clinical practice it varies more widely, e.g. depending on the size of the body part examined. In digital luminescence radiography the inherent linear response curve of the storage phosphor and the ability to manipulate the images displayed result in high tolerance to variations in exposure, reducing the number of films that must be repeated due to inadequate exposure. The advantages of digital imaging combined with picture archiving and communication systems (PACS) in an acute trauma setting include no lost films, immediate and simultaneous

access to the images by several physicians, easy storage, retrieval of images and reports, and comparison with previous digital studies (Bryan et al. 1999).

2.3.1.2 Projections

Radiographs taken after the clinical examination in 2 projections perpendicular to each other are generally the first and in many cases the only diagnostic images needed for the evaluation of trauma. Complex anatomic joint structures such as those in the wrist, elbow, shoulder, ankle, and foot may sometimes need special projections to eliminate superimposed structures. In the evaluation of joints at least 3 views are recommended to assess the potential injury: frontal, lateral, and appropriate oblique (Rogers and Kaye 2001).

For radiographic examination of the wrist several authors proposed 4 views: posteroanterior (PA), PA with ulnar deviation, lateral, and pronation-oblique projections (Rogers and Kaye 2001). If scaphoid fracture is suspected, the standard views of the wrist in 2 projections and an additional coned-down view (Stecher view of the scaphoid) are recommended (Bohndorf et al. 2001). A total of 2-16% of scaphoid fractures are not visible on primary radiographs (Mittal and Dargan 1989, Tiel-van Buul et al. 1993). If symptoms persist for more than 2 weeks, and especially if pain and swelling are present, radiographic examination should be repeated.

Examination of the elbow should include AP, lateral, and external oblique views. The angled lateral view acts as a supplement to the external oblique view and is a better way to locate occult fractures of the radial head and other fractures (Greenspan and Norman 1987).

Special projections are used more in the shoulder region than in any other joint. In the case of shoulder trauma the most common standard projections used are the true AP view of the glenohumeral joint perpendicular to the plane of the scapula and the axillary view parallel to this plane. AP internal and external rotation views may be helpful in visualizing different aspects of the humeral head but are difficult to obtain in cases of acute injury (Hoffmeyer 2002). The axillary, scapular Y (transscapular), or transthoracic lateral views help clarify the position of the humeral head in relation to the glenoid.

Radiographs of the ankle must include AP, 20° internal oblique (mortise), and a lateral view that includes the base of the fifth metatarsal. The assessment of tarsal injuries should include AP, lateral, and oblique views of the foot.

In general, diagnosis of fracture can be performed quickly using radiographs and it provides relevant information as to whether the adjacent joint is involved and how the fracture fragments are positioned. However, in multitrauma patients and in severe comminuted joint fractures the quality of the radiographs may suffer from inappropriate positioning of the joint due to pain and from soft-tissue swelling of the acutely injured joint (Norfray et al. 1981, Laasonen and Kivioja 1991). Therefore, additional imaging with other modalities is necessary in these cases.

2.3.2 Computed tomography (CT)

CT was introduced in the 1970s into the field of diagnostic imaging (Ambrose and Hounsfield 1973). CT images are constructed from projections obtained while measuring the transmission of x-rays through an object. On their way through the tissues, x-rays are attenuated, mainly due to absorption and scattering. The main advantages of CT are its ability to distinguish objects in slices

or cross-sectional images according to their position in the projection direction and to resolve objects with very small contrast. Conventional axial CT generates tomographic images, without interference from superimposed structures, by sequential scanning, usually along the axial plane. The problems involved with conventional axial CT in the assessment of fractures are several. Fractures running in the axial plane (the plane of the scan) or tube movement may be invisible due to volume averaging (a fracture line may lie entirely within the length of the pixel of the scanned section) and fractures in the long axis of the body are difficult to visualize and appreciate without MPR (Rogers 1992). Spiral computed tomography (SCT) was introduced in 1990 as a new technique for continuous-volume data acquisition (Kalender et al. 1990).

CT has almost replaced conventional tomography as an adjunctive imaging method in various traumatic abnormalities of the joints. After standard axial sections are obtained in single-slice SCT, reformation images in additional imaging planes (MPR) can be acquired and 3-D reconstruction can be performed. The problem with single-slice SCT is the inverse relationship between scan volume and slice thickness or spatial resolution. It causes reformation artifacts in volumetric imaging (MPR and 3-D reconstruction), due to poor spatial resolution along the patient axis. Consequently direct sagittal and coronal imaging of the traumatized joint, if possible, are preferable to reformation techniques in single-slice CT scanning.

CT is effective in demonstrating subluxations in the distal radioulnar joint and occult scaphoid and other carpal bone fractures (Mino et al. 1983, Jonsson et al. 1992). Direct oblique sections can be obtained with the wrist in maximal volar flexion or dorsal extension.

Axial CT images of the extended elbow are occasionally effective in demonstrating traumatic abnormalities in the joint but are sometimes difficult to obtain in the traumatized elbow due to pain

(Greenspan 2000). Direct coronal (flexed elbow) single-slice SCT images provide an ideal plane for anterior evaluation of the radial head, capitellum, and trochlea (Franklin et al. 1988) and true sagittal images can be obtained by placing the patient in the prone position on the CT table with the arm around and under the table (Garniek et al. 1995).

When radiographs provide inadequate information on complex proximal humeral fractures, a CT scan can be used. Axial CT images better demonstrate the displacement, rotation, and integrity of the articular surfaces (Castagno et al. 1987, Kilcoyne et al. 1990). Axial CT scans are also superior to plain images in assessing the sizes of bony defects of the glenoid rim (Itoi et al. 2003) and the integrity of the glenoid cavity in suspected intraarticular extension of scapular neck fractures (McAdams et al. 2002).

For adequate single-slice CT of the ankle and foot, proper positioning of the leg in the gantry is essential. For coronal images the knees are flexed and the feet are positioned flat against the CT table and for axial images the feet are perpendicular to the table (knees extended). Appropriate positioning of the ankle and foot for true axial and coronal scans can be difficult in severe traumas. Single-slice SCT with true axial and coronal images is effective in assessing complex fractures of the distal tibia, talus, calcaneus, and tarsometatarsal joint (Magid et al. 1990, Janzen et al. 1992, Wechsler et al. 1997, Preidler et al. 1999). However, in intraarticular calcaneal fractures the degree of depression of the posterior calcaneal facet may often be underestimated in lateral radiographs and also in coronal CT images (Rosenberg et al. 1987, Ebraheim et al. 1996).

2.3.2.1 Multidetector computed tomography (MDCT)

MDCT was introduced in 1998 (Klingenberg-Regn et al. 1999, Hu et al. 2000) and improved the relationship between scan duration, available scan length, and spatial resolution along the patient axis (z-axis). In comparison to single-slice SCT, MDCT allows for simultaneous acquiring of multiple sections within a single tube rotation and all scanners offer subsecond rotation speed, thus increasing the performance substantially (Fig. 6). The increased performance of MDCT can be invested in shorter data acquisition (faster scans), wider scanning ranges (longer scans), or smaller sections (thinner scans). Faster scanning reduces movement artifacts and longer scans can be taken in a single breath-hold, especially benefiting emergency trauma patients (Novelline et al. 1999, Rydberg et al. 2000). Thinner sections make it possible to acquire a near isotropic dataset with high spatial resolution and reduced partial volume effects (Flohr et al. 2002, Mahesh 2002), that allow volumetric imaging and reconstruction of arbitrary MPRs. The position of the body part scanned (e.g. the joint) is not crucial, due to use of these high-quality reformats.

Hallscheidt et al. (2003) reported in their ex vivo study that MDCT can provide spatial resolution of 0.23 mm (isotropic voxel size), but in clinical practice the isotropic resolution of MDCT for most applications is generally 0.5 mm at best (Prokop 2003). Volumetric imaging is optimized for high spatial resolution along the patient axis and requires scanning with a thin-slice collimation of 1.25 mm or below and reconstruction of overlapping thin-section datasets (Prokop 2003). To reconstruct an isotropic data grid, the reconstruction increment (RI) should be similar to the pixel size, which is derived from the field of view (FOV) and the matrix size (usually 512):

$$RI = FOV/matrix\ size$$

Image noise grows as section collimation is reduced and to maintain a low level of noise, either the radiation dose needs to be raised or thicker sections reconstructed. In clinical practice, thicker sections are reconstructed from raw data, either axially or in any desired plane using MPR functionality.

The increased performance of the MDCT technique yields a substantial volume of data that requires new ways of viewing, processing, archiving, and demonstrating images (Rubin 2000). PACS allows easy storage and retrieval of the images and with modern workstations and mouse-scrolling techniques the total evaluation time of a single set of several hundred images is kept in the same or even lower range as with single-slice scanning (Prokop 2003).

Fig. 6. Schematic pictures of detector designs in different types of CT scanners. The detectors are arranged in the x-y plane in an approximately 50° arc opposite the X-ray tube. In MDCT scanners, each detector in the x-y plane is segmented along the z-axis (gridlike detector assembly).
A, Conventional axial CT and single-slice SCT scanners.
B, MDCT (4-detector) scanner.
Modified from Saini and Dsouza 2003.

2.3.2.2 MDCT in trauma

The widespread availability, speed, and versatility of MDCT make it an ideal imaging modality in emergency radiology. The standardized whole-body trauma examination protocol in which head, cervical spine, thorax, and abdomen are MDCT-scanned in high-energy multitrauma patients, has already lead to improved care and decreased mortality (Klöppel 2002). MDCT has also become a useful imaging modality in complex pelvic fractures (Falchi and Rollandi 2003) and in traumatic head and neck lesions (Mack et al. 2003). However, the value of MDCT in the imaging of acute joint fractures has not yet been assessed.

2.3.3 Magnetic resonance imaging (MRI)

MRI is an ideal imaging modality for the musculoskeletal system, because various tissues display different signal intensities in T1 (longitudinal relaxation)- and T2 (transverse relaxation)-weighted images. In conventional spin echo imaging, T1-weighted images (short repetition time (TR) and short time-to-echo (TE)) generally demonstrate favorable anatomical images due to relatively high signal-to-noise ratio coupled with good tissue contrast. T2-weighted images (long TE and TR), on the other hand, demonstrate water content, e.g. fluid collections, in various tissues. These images are useful in detecting pathological processes in the tissues. Fat-suppression techniques are used to reduce the signal from fat and are utilized in T2-weighted images to differentiate pathological water content processes, such as bone marrow edema in the subchondral bone, from fat (Fleckenstein et al. 1991).

Compared with conventional radiography, low-field MRI is superior in detecting fractures near large joints such as the knee, elbow, ankle, wrist, and distal radius but it has lower accuracy for the

detection of lesions in small bones such as the digits (Remplik et al. 2004). Boniotti et al. (2003) showed that MRI is the most sensitive and specific imaging modality in bone microinjuries (cortical and spongy bone fissures in stress or insufficiency fractures) compared with radiographs, radionuclide bone scans, and CT. However, there have been no studies comparing MDCT with MRI for assessing acute joint fractures.

MRI is considered to be the method of choice in traumatic injuries of the distal extremities (Klein 1993, Bertlau et al. 1999, Bohndorf 1999, Bohndorf and Kilcoyne 2002) and has distinct advantages over CT, due to superior soft-tissue contrast and lack of ionizing radiation. The soft-tissue contrast resolution of CT allows the differentiation of ligaments and tendons from the surrounding fat, but MRI has proved to be superior to CT of these structures and for evaluation of traumatic muscle lesions (Rosenberg et al. 1988, El-Khoury et al. 1996, Farooki and Seeger 1999). MRI is the method of choice in imaging of the shoulder if posttraumatic labral and rotator cuff lesions are suspected (Bohndorf and Kilcoyne 2002). MRI is also an effective method of demonstrating occult wrist fractures (Breitenseher and Gaebler 1997, Steinbach and Smith 2000, Dorsay et al. 2001), although false-negative triquetral fractures have been reported (Lohman et al. 1999). In the imaging of elbow trauma MRI is superior for assessing injuries to the ligaments, tendons, and cartilage (Potter 2000). In pediatric patients with immature skeletal systems, elbow fractures are often different types of Salter-Harris fractures, in which case MRI is the best imaging modality (Potter 2000, Griffith et al. 2001).

The problem with MRI is its cost and availability, especially at on-call hours. CT is also a faster imaging modality than MRI, which is a crucial point in trauma patients. Metallic fixation material and even very small particles of ferromagnetic material in operated joints produce artifacts in MRI images (Alanen et al. 1995). Metallic fixation material also causes artifacts in CT images, but in

MDCT the metal artifact problem can be diminished using thinner sections and image-processing techniques.

2.4 Treatment of acute joint trauma

Most joint injuries can be managed conservatively in the primary care setting. Immobilization, rest, ice, compression, and elevation are the immediate means of treatment given for a joint injury. Referral to an orthopedic specialist is usually indicated in cases of fractures involving the articulating surface, moderate to severe joint instability, or locking of the joint. Occult fractures may be potentially damaging and their delayed and ineffective management can cause sequelae such as chronic pain, instability, and arthrosis.

In general, non- or minimally dislocated fractures can be treated conservatively with cast and immobilization, whereas dislocated intraarticular and complex fractures usually need surgical management. Primary radiographs and possible complementary imaging modalities, such as CT or MRI, should show the extent of the fractures and the degree of joint incongruence to aid in surgical planning and decisionmaking. In complex fractures the spatial relationship among fracture fragments should be well delineated in these images to aid in correcting reduction of the dislocated joint facets and screw placement.

3. AIMS OF THE PRESENT STUDY

The purposes of the present study were to assess the value of MDCT in the imaging of

1. wrist fractures (I),
2. elbow fractures (II),
3. shoulder fractures (III),
4. ankle and foot fractures (IV), and
5. Lisfranc fracture-dislocations (V),

compared with conventional radiography in patients referred to a level-one trauma center.

4. MATERIALS AND METHODS

All retrospective studies (I-V) were undertaken at Helsinki University Central Hospital, HUS Helsinki Medical Imaging Center, Töölö Hospital, Helsinki, Finland, and were approved by the Medical Ethics Committee of Helsinki University Central Hospital.

4.1 Patients

In level one-trauma centers, which are dedicated to the treatment of severe orthopedic and neurosurgical trauma, a specialized team including orthopedic surgeon, neurosurgeon, anesthesiologist, and radiologist and all trauma-imaging modalities (including CT and digital subtraction angiography with 24-hour availability of transcatheter embolization in exsanguinating pelvic bleeding) are available 24 hours per day, 7 days per week. Töölö Hospital serves as the only level-one trauma center for a population of 1.4 million people and is the leading level-one trauma center in Finland. In addition, some of the most difficult cases of orthopedic and neurosurgical trauma are referred to Töölö Hospital from all over the country. Pediatric patients, usually under the age of 16 years, are primarily taken to Children's Hospital and therefore were not included in these studies.

All patients in the present study (I-V) were treated and imaged on a clinical basis at Töölö Hospital. The patients were referred to Töölö Hospital emergency room from primary healthcare units, private health care units, or brought by ambulance or helicopter directly from accident locations. Clinical examination was performed by an orthopedic surgeon, orthopedic surgical residents, or postgraduate fellows. All imaging (MDCT and radiography) was performed on a clinical basis and by requests of the above-mentioned physicians. The MDCT examinations were requested to

confirm or rule out a suspected fracture based on plain radiographs or to reveal the complex fracture anatomy to aid in planning surgery or deciding between surgery and more conservative management. All emergency room MDCT requests were retrieved, using PACS and Agfa Impax 4.1 DS 3000 1Mb High Brightness monitors (1280 x 1024), and patients with acute joint (wrist, elbow, shoulder, or ankle and foot) injury and who underwent MDCT in the primary phase were included in this study.

Most of the patient population in this study was retrieved in the 37-month period since installation of the MDCT in Töölö Hospital in August 2000 to late August 2003, and during that time 7139 MDCT examinations were performed in Töölö Hospital at the request of the emergency room physicians. The number of more complicated joint fractures is pronounced in this study, due to the high-energy trauma patient population treated in the level-one trauma center and that more simple joint injuries and fractures are treated based on plain radiographs and do not undergo MDCT. Two musculoskeletally oriented radiologists (VH, MK) re-evaluated retrospectively and by consensus the imaging studies (MDCT and radiographs) by fracture location, type, and injury mechanism. Primary radiographs of the joint, when available, were re-evaluated by consensus and were then compared with the MDCT findings. A few of the primary radiographs were unavailable because they were taken in primary or private health care units (film prints) and were not stored afterwards in digital archives as should have been done. In the present study the diagnosis of acute traumatic joint fracture was based on MDCT, which was regarded as the gold standard in diagnostic imaging. The sensitivity of MDCT in acute joint fractures compared with MRI findings could not be assessed here because joint MRI examinations were not generally performed in this study population.

I

All emergency room CT requests in Töölö Hospital from August 2000 to late May 2003 were retrieved and patients with a wrist injury who were MDCT-scanned in the primary phase were included in this study. Thirty-eight patients (24 male, 14 female, age 21-73 (mean 40) years) met the inclusion criteria.

II

Emergency room CT requests from August 2000 to late May 2003 were retrieved and patients with an acute elbow injury who underwent an elbow MDCT in the primary phase were included in the study. The elbow MDCT examinations were requested by emergency room physicians for clinical reasons, mainly to reveal complex fracture anatomy or to rule out a fracture. Fifty-six patients (32 male, 24 female, age 16-88 (mean 44) years) met the inclusion criteria.

III

All emergency room CT requests from August 2000 to late August 2003 were retrieved and patients with an acute shoulder injury who underwent shoulder MDCT in the primary phase were included in the study. The shoulder MDCT examinations were requested by emergency room physicians mainly to confirm or rule out a suspected fracture based on plain radiographs or to reveal the complex fracture anatomy. A total of 210 patients (128 male, 82 female, age 16-95 (mean 51.7) years), met the inclusion criteria. Acromioclavicular joint dislocations and clavicular fractures were not included in this study.

IV

All emergency room CT requests from August 2000 to late August 2003 were retrieved and patients with an acute ankle and foot injury who underwent an ankle and foot MDCT in the primary phase

were included in the study. The ankle and foot MDCT examinations were requested by emergency room physicians mainly to reveal complex fracture anatomy or to rule out a fracture. A total of 388 patients (282 male, 106 female, age 16-89 (mean 40) years) met the inclusion criteria.

V

A total of 282 patients (208 male, 74 female, age 13-89 (mean 42) years) who underwent foot and ankle MDCT in the primary phase, were retrieved from all emergency room CT requests between August 2000 and December 2002. Nineteen patients (7%) had Lisfranc fracture-dislocation and were included in the study. The MDCT scans were requested by emergency room physicians for clinical reasons, mainly to reveal complex fracture anatomy in multitrauma patients.

4.2 Methods

4.2.1 Radiography

The following standard primary radiographs were obtained:

1. Wrist (I) PA and lateral projections and, if scaphoid fracture was suspected, an additional coned-down view (Stecher view of the scaphoid).
2. Elbow (II) AP and lateral projections and, if not restricted by pain, external oblique projection.
3. Shoulder (III) AP, scapular Y, and, if posterior dislocation was suspected, axial projections.
4. Ankle (IV,V) AP, 20° internal oblique (mortise), and lateral projections and foot (IV,V) AP, oblique, and lateral projections.

4.2.2 MDCT

All patients underwent CT on a 4-section multidetector scanner (LightSpeed QX/i; GE Medical Systems, Milwaukee, WI, USA). Routine MDCT examinations of the joints were performed as presented in Table 1. Wrist and elbow MPRs were done in standard coronal and sagittal planes. Shoulder MPRs were done in standard coronal oblique (perpendicular to glenoid articular surface) and sagittal oblique (parallel to glenoid articular surface) planes. MPRs of the ankle and foot were done in standard coronal (straight coronal plane perpendicular to tibial plafond in distal tibial fractures and oblique coronal plane perpendicular to posterior talocalcaneal facet in calcaneal fractures) and sagittal planes in the ankle and in the axial and sagittal planes in the foot. The 3-D reformats were done when requested by the operating orthopedic surgeon.

Fracture classification was based on the MDCT findings. One or several fractures in the same bone were calculated as one fracture per bone in the statistical analysis except in IV, where fractures were calculated according to 5 anatomic regions: ankle (malleolar, tibial pilon, and Tillaux fractures), calcaneus, talus, midfoot (navicular, cuboid, and cuneiform bone fractures), and forefoot (metatarsal bone fractures).

Table 1
Acquisition and reconstruction parameters for MDCT of the joints

	Slice collimation (mm)	Table feed/rotation speed* (mm)	Pitch**	Width of MPR (mm)	Reconstruction increment*** (mm)
Wrist	4 x1.25	3.75	0.75	1.0	1.0
Elbow	4 x1.25	3.75	0.75	1.0	1.0
Shoulder	4 x2.5	7.5	0.75	2.0	2.0
Ankle and foot	4 x1.25	3.75	0.75	1.0	1.0

* Rotation speed = one gantry rotation per second

** Pitch = Table feed /slice collimation

*** Distance between reconstructed MPR views

5. RESULTS

The number of patients and of fractures related to anatomical location are shown in Table 2.

5.1 MDCT in wrist fractures (I)

MDCT revealed 56 wrist fractures and 7 wrist dislocations in 29 patients. Twenty (36%) of 56 wrist fractures occurred in the small carpal bones. Twenty-nine (76%) of 38 patients had a wrist fracture, and in 9 patients (24%) the MDCT was normal. Eighteen patients (62%) had multiple fractures in the wrist joint (more than one bone fractured) and 11 patients (29%) were operatively treated. The 3 most common injury mechanisms were falling in 22 patients (58%), a fall from a height in 6 (16%), and sports activity in 3 (8%).

Primary radiographs were available for 33 patients (87%). In 4 patients (14%) MDCT revealed 9 occult fractures in the wrist compared with primary radiography: 2 each in the trapezoidium and capitulum, one each in the hamate, trapezium, and metacarpal V, and one each in the metacarpal III and IV fracture-subluxation. In 14 (37%) of 38 patients a wrist fracture initially suspected based on radiography was shown by MDCT not to be present (false-positive), 7 cases (50%) of these false-positive findings were in the scaphoid. In 3 patients (8%) with a normal primary radiograph, MDCT examination was performed on clinical suspicion of a scaphoid fracture. In the first of these cases MDCT was also normal; in the second MDCT showed scaphoid and trapezium fractures (Fig. 7) and in the third a trapezoid fracture.

Table 2

Number of patients and of fractures related to location

	No. of patients	No. of patients with fractures (%)	No. of fractures
Wrist	38	29 (76)	56
Elbow	56	48 (86)	65
Shoulder	210	191 (91)	311
Ankle and foot	388	344 (89)	517
Total	692	612 (88)	949

Fig. 7. A, Normal AP radiography of the wrist. B-C, Coronal and D, sagittal MPR images reveal scaphoid (arrows) and trapezium (arrowheads) fractures.

5.2 MDCT in elbow fractures (II)

MDCT revealed 65 fractures in 56 patients and 3 main fracture types were established: 16 ulnar coronoid process fractures (25%), 13 radial head fractures (20%), and 12 humeral supracondylar fractures (18%). Forty-eight (86%) of these 56 patients had an elbow fracture, of which 14 (29%) also had multiple fractures in the elbow joint and 27 (56%) received surgery. Seven patients (13%) also had injuries to other parts of the body. Three main injury mechanisms included falling in 38 patients (68%), falling from a height in 6 (11%), and traffic accidents in 5 (9%).

Primary radiographs were available for 54 patients (96%): one multitrauma patient was scanned immediately with MDCT and in one patient primary radiography was not available. In 6 patients (11%) MDCT revealed 13 occult fractures in the elbow joint compared with primary radiography: 3 in the ulnar coronoid process, 2 in the proximal ulnar, 2 in the humeral capitulum, one each in the trochlea and supracondyle, and 4 in the radial head. In 4 patients (7%) a displaced fracture fragment was detected in primary radiography but the origin of the fragment was unclear. In all 4 cases, MDCT revealed the origin of the fragment. In all fractures, MDCT showed the anatomy of the joint better than in the primary radiographs, especially in complex fractures of the distal part of the humerus, where the MPR revealed the fracture morphology more accurately than radiographs. The number of fractures detected in MDCT versus primary radiography and their distribution are shown in Table 3.

Table 3

Number of fractures in various elbow regions detected in MDCT versus primary radiography

	Fractures in MDCT	Radiography true- positive	Sensitivity of radiography (%)
Humerus	25	21	84
Supracondylar	12	11	92
Intracondylar	1	1	100
Epicondylar	3	3	100
Trochlear	1	0	0
Capitulum	8	6	75
Ulna	25	18	72
Coronoid process	17	13	76
Olecranon	3	3	100
Proximal ulna	5	2	40
Radius	15	9	60
Head	15	9	60

5.3 MDCT in shoulder fractures (III)

MDCT revealed a total of 311 fractures, 152 in the scapula and 159 in the proximal humerus, in 191 (91%) of 210 patients scanned. Of these 191 patients, 112 (59%) had multiple fractures (more than one bone fractured) in the shoulder region and 81 (42%) were treated operatively. Three main injury mechanisms were established in these patients: falling in 113 (54%), traffic accidents in 36 (17%), and falling from a height in 12 (6%). In 15 patients (7%) a fracture was suspected in primary radiography, but in MDCT these cases were shown to be false-positives.

Primary radiographs were available for 197 patients (94%). Table 4 lists the number of fractures in various scapular regions detected in MDCT and primary radiography. The 3 most common occult fractures in the scapula were fractures of the coracoid process, scapular spine, and glenoid cavity for which the sensitivity of the radiography was 40-65%. The glenoid was the most commonly fractured part of the scapula for which the overall sensitivity of radiography was 88% compared with MDCT. The sensitivity of radiographs for bony Bankart lesions was good (95%) but only moderate in other glenoid cavity fractures (65%). In 8 patients (4%) a bony Bankart lesion was suspected in primary radiography, but these cases were shown to be false-positives in MDCT.

The number of fractures in the proximal humerus detected in MDCT and in primary radiography are shown in Table 5. The 3 most common occult fractures in the proximal humerus were fractures of the lesser tubercle, head splitting, and posterolateral compression fracture (Hill-Sachs lesion) in the head of the humerus for which the sensitivity of the radiography was 8-53%. MPR revealed the number and position of the dislocated fracture fragments better than conventional radiography, especially in complex comminuted (more than 2 fractures) of the proximal humerus fractures. A total of 35 patients (17%) had a comminuted fracture of the proximal humerus and in 20 (63%) of

32 patients with radiographs available the exact number of fracture fragments was underestimated in primary radiographs compared with the MDCT findings. In 12 patients (6%) a displaced fracture fragment was detected in radiography, but the origin of the fragment was unclear; in all 12 cases MDCT revealed the origin of the fragment.

In all, 66 patients (31%) showed anterior dislocation of the shoulder (one bilateral dislocation) and a fracture was included in 60 cases (90%). The 3 most common fractures with anterior dislocation were the Bankart lesion in 35 cases (58%), Hill-Sachs lesion in 34 cases (57%), and fracture of the greater tubercle in 20 cases (33%). Posterior dislocation was detected in 13 patients (6%) and a fracture was included in all these cases: 7 anteromedial compression fractures (reverse Hill-Sachs lesions) in 54%, 5 lesser tubercle fractures (38%), and 3 humeral surgical neck fractures (23%). The sensitivity of conventional radiography for the detection of posterior dislocation was 88% (7 cases out of 8) compared with MDCT.

Table 4

Number of fractures in various scapular regions detected in MDCT versus primary radiography

	Fractures in MDCT	Radiography available	Radiography true-positive	Sensitivity of radiography (%)
Glenoid	78	75	66	88
Anteroinferior part	60	58	55	95
Cavity	18	17	11	65
Acromion	7	7	6	86
Coracoid process	10	10	4	40
Scapular neck	12	11	9	82
Scapular wing	36	34	32	94
Scapular spine	9	7	4	57

Table 5

Number of fractures in proximal humerus detected in MDCT versus primary radiography

	Fractures in MDCT	Radiography available	Radiography true-positive	Sensitivity of radiography (%)
Hill-Sachs	43	40	21	53
Reverse Hill-Sachs	10	8	6	75
Head splitting	3	3	1	33
Greater tubercle	52	48	39	81
Lesser tubercle	15	13	1	8
Anatomical neck	2	2	2	100
Surgical neck	34	31	28	90

5.4 MDCT in ankle and foot fractures (IV)

A total of 517 fractures were found in all 5 anatomic regions: ankle, calcaneus, talus, midfoot (navicular, cuboid, and cuneiform bones), and forefoot (metatarsal bones). A total of 344 (89%) of the 388 patients had one or more fractures in the ankle or foot. Nine patients (3%) had talocrural fracture-dislocation and 12 (3%) had luxation of Chopart's joint (one case was bilateral). Twenty-four patients (7%) had Lisfranc fracture-dislocation and 2 of these patients also had a bilateral tarsometatarsal fracture-dislocation. The 3 main injury mechanisms were falling from a height in 164 patients (48%), a simple fall in 68 (20%), and a traffic accident in 47 (14%).

Primary radiographs were available for 296 patients (86%) with fractures. The number of fractures detected in MDCT versus primary radiography according to location is shown in Table 6. The 3 most common occult fractures in the ankle not detected in primary radiography were isolated fractures of the posterior and medial malleolus and Tillaux fracture, for which the sensitivity of the primary radiography was 50-72%. The calcaneus was the most commonly fractured bone in this study, and the overall sensitivity of radiography was 87% in this fracture group compared with MDCT. MDCT with coronal and sagittal MPR revealed the extent of the fractures and the position of the dislocated posterior calcaneal facet better than conventional radiography, especially in cases of complex intraarticular fracture patterns.

The overall sensitivity of radiography for the detection of talar fractures was 78% compared with MDCT. Eight talar fractures (11%) out of 73 were associated with subtalar joint dislocation, and the intraarticular fracture was detected in 7 of 8 cases in primary radiography. The total number of luxations of Chopart's joint was 13 (3%), and 5 cases were associated with navicular intraarticular fracture; no fractures of the corresponding talar joint facet were seen in patients with Chopart's joint

luxation. Only one of 4 intraarticular navicular bone fractures was shown on radiographs. Therefore, intraarticular fractures in subtalar or talonavicular dislocations were seen in conventional radiography in 8 of 12 cases. In the detection of midfoot fractures, the sensitivity of primary radiography was 25-33% compared with MDCT. The total number of Lisfranc fracture-dislocations was 26 (5%), and an occult Lisfranc fracture-dislocation was detected in 5 cases (24%) in MDCT, because primary radiographs were available in 21 cases.

Table 6

Number of fractures in ankle and foot detected in MDCT versus primary radiography

	Fractures in MDCT	Radiography available	Radiography true-positive	Sensitivity of radiography (%)
Lateral malleolus	30	25	22	88
Medial malleolus	20	18	13	72
Posterior malleolus	18	16	10	63
Anterior tibial	8	5	4	80
Bimalleolar*	14	10	8	80
Medial malleolus	14	10	9	90
Lateral malleolus	14	10	8	80
Trimalleolar*	16	16	13	81
Medial malleolus	16	16	15	94
Lateral malleolus	16	16	15	94
Posterior malleolus	16	16	15	94
Tibial Pilon	30	27	26	96
Tillaux	15	14	7	50
Talus	73	67	52	78
Calcaneus	187	149	129	87
Navicular bone	34	30	10	33
Cuboid bone	27	24	6	25
Cuneiform bones	37	33	8	24
Metatarsal bones	66	57	48	84

* primary radiography was classified as negative if none of the fractured malleoli were shown

5.5 MDCT in Lisfranc fracture-dislocation (V)

A total of 21 Lisfranc fracture-dislocations were found in 19 patients. Additional foot and ankle fractures were seen in 9 cases (43%), and 9 patients (47%) had severe injuries or fractures in other parts of the body. Two main injury mechanisms were established: falling from a height in 10 cases (48%) and traffic accidents in 5 cases (24%).

Primary radiographs were available for 17 cases (81%); 2 patients were scanned immediately with MDCT because of multiple injuries to the lower limbs and body. In 2 patients primary radiographs were not available. Lisfranc fracture-dislocation was not shown in primary radiography in 4 (24%) of 17 cases (Fig. 8). Compared with true-positive primary radiography, MDCT revealed additional occult fractures in the Lisfranc joint in 6 (46%) of 13 cases. In addition to the 13 true-positive radiographic results, 5 Lisfranc fracture-dislocations were suspected in primary radiographs but were proven to be false-positives in MDCT. MDCT also revealed additional occult fractures in other parts of the foot and ankle in 6 (35%) of 17 cases: one talar, 2 calcaneal, and 4 navicular fractures. MDCT with MPR provided better visualization of the complex fracture anatomy and of even minimal joint malalignment of the Lisfranc joint without interference from superimposed structures. The extent of the fractures and of the dislocated joint facets of all Lisfranc fracture-dislocations was better evaluated with MPR than in radiographs.

Fig. 8. A, AP radiography shows no evidence of metatarsal or tarsal fractures or joint malalignment. B, Lateral radiography shows Chopart's luxation (arrow) but no signs of Lisfranc fracture-dislocation. C-D, Axial MPR of the foot reveals lateral shift of the second metatarsal base (long arrow) and widened space between the first and second metatarsal bones and intraarticular fracture of the intermediate cuneiform bone (arrowhead) in Lisfranc fracture-dislocation. Note also lateral malleolus fracture (short arrow).

6. DISCUSSION

6.1 MDCT in acute joint fractures

CT is an imaging technique commonly used after radiography in the setting of joint fracture. The uncertainty of joint radiographs in the trauma patient may stem from poor positioning due to pain, poor-quality radiographs due to soft-tissue edema, or disagreement between the patient's symptoms and the radiographic findings. The role played by CT can be divided into cases where in radiography the presence of a fracture is in doubt and those where the diagnosis is performed but CT is used to better define the extent of injury to aid in planning for surgery or in deciding between surgery and more conservative management. MDCT is faster and makes use of high-quality MPR and isotropic viewing compared with single-slice SCT. MDCT also has fewer motion artifacts, reduced partial volume effects, and decreased image noise compared with single-slice SCT, all of which increases the diagnostic power of this imaging modality to benefit emergency trauma patients (Novelline et al. 1999, Rydberg et al. 2000). The high-quality MPR capability is especially useful in analyzing complex joint fractures where complicated spatial information on the relative positions of fracture fragments can be easily demonstrated to orthopedic surgeons, thus aiding in surgical planning. MPR also better reveals the subtle fractures, particularly those oriented in the axial plane. Positioning of the patient and joint on the scanning table is not crucial in MDCT, due to use of excellent quality reformats. Therefore, sagittal and coronal reformats are routinely included in Töölö Hospital where CT technologists perform these standard MPRs, and radiologists, if needed, perform the additional MPRs.

MRI has a major impact on diagnosing traumatic joint injury and has distinct advantages over CT, due to superior soft-tissue contrast and lack of ionizing radiation (Bohndorf and Kilcoyne 2002).

The problem with MRI is its cost and availability. The availability of MDCT is, in general, better than that of MRI, especially at on-call hours. MDCT is also a faster imaging modality than MRI, which is a crucial point in trauma patients, especially in multitrauma patients.

Radiation dosage is substantially increased in MDCT if the same milliamperage settings as in single-slice CT are used (McCollough and Zink 1999), but conscientious choice of scanning parameters and optimizing the scan protocols can eliminate or reduce this problem. The average effective radiation dose for extremity MDCT examination is 1 mSv (Nagel 2002), which is dependent on the size and length of the body part examined and the scanning parameters used (slice thickness, voltage, amperage). The effective dose for extremity radiography is approximately 0.01 mSv (European Commission 2001). Although the effective dose is higher in MDCT examination than in conventional radiography, the extremity MDCT examination can also be considered as a low-dose examination (European Commission 2001). In the setting of a high-energy multitrauma patient where head, cervical spine, thorax, and abdomen are MDCT-scanned, the relative dose for extremity MDCT examination is small compared with the total body radiation dose.

6.1.1 Wrist

Adult wrist fractures most commonly involve the distal forearm and especially the distal radius (Greenspan 2000), which was also the predominant fracture type in the present study. The incidence of small carpal bone fractures was higher in the present study than would have been expected, based on the previously published studies (Greenspan 2000). This was probably due to our patient population; simple distal forearm fracture patients are not usually treated in a level-one trauma center and do not undergo MDCT, which was the case here.

In clinical practice, distal radius fractures seldom cause diagnostic problems in radiographs. However, small carpal bone fractures can be difficult to detect, due to complex joint anatomy and overlapping shadows. In the present study MDCT showed occult fractures and enabled ruling out of suspected fractures, both mainly in the small carpal bones. Scaphoid fracture may be occult and if unrecognized may lead to complications such as nonunion, osteonecrosis, and posttraumatic arthritis (Langhoff and Andersen 1988, Filan and Herbert 1995, Gaebler et al. 1996). Several special radiography views have been described to better image the scaphoideum and other small carpal bones. Although these special views increase diagnostic accuracy (Brondum et al. 1992), MDCT with MPR in the sagittal and coronal planes show the wrist anatomy without superimposed structures and occult fractures are therefore more easily revealed. In special radiography views, the positioning of the wrist and hand is important, which can be painful and difficult for the patient. In MDCT positioning of the wrist and hand is not crucial, due to the use of high-quality reformats.

In the setting of equivocal primary radiographs and clinical suspicion of a fracture, MDCT can be used to confirm or rule out a fracture and in the latter case unnecessary cast immobilization and later control radiographs can be avoided, as was seen in this study. However, in the case of equivocal primary radiographs, cast immobilization (and control radiographs) should remain the mainstay in the treatment of suspected scaphoid fractures until MDCT becomes generally accepted as the gold standard for imaging methods in scaphoid fractures. Thus far no studies are available in which MDCT is compared with MRI in the assessment of scaphoid fractures. MRI has also been considered as a good problem solver in occult wrist fractures (Breitenseher and Gaebler 1997, Steinbach and Smith 2000, Dorsay et al. 2001), although false-negative triquetral fractures have been reported (Lohman et al. 1999). However, MDCT is a faster imaging modality and its availability is better compared with MRI.

6.1.2 Elbow

Adult elbow fractures most commonly involve the radial head (Harris Jr 2000, Kandemir et al. 2002) and the injury mechanism is usually a fall (Morrey et al. 1988). Falling was also the most common injury mechanism in the present study, but the most common fracture type was the ulnar coronoid process fracture. This can be explained by the patient population; simple nondisplaced radial head fractures can be treated conservatively and are not usually referred to a level-one trauma center. The radial head fracture was the second most common fracture type in this study, although the humeral supracondylar fracture was almost as frequently seen.

Fractures of the radial head and neck may be subtle, and the appearance of secondary signs in primary radiographs, such as the elevated fat pads from elbow joint effusion, may be the only signs indicating a fracture (Harris Jr 2000, Major and Crawford 2002). Radial head fracture was the most common occult fracture (sensitivity of radiography 69%) in this study, constituting 31% of all occult elbow joint fractures. Fracture of the coronoid process may be occult and is most often associated with posterior dislocation in the elbow joint. If unrecognized it may fail to unite, leading to recurrent subluxation or dislocation in the joint (Greenspan 2000); therefore identification of ulnar coronoid fracture is important.

Displaced fracture fragments in the elbow joint are usually detected easily in radiographs but small ulnar coronoid fragments can be difficult to distinguish from fragments of the radial head. The origin of the fragment can be a diagnostic problem for radiography, as it was in 4 patients in this study. MPR in the sagittal and coronal planes shows the joint anatomy without interference from superimposed structures and the origin of the fragment is more easily revealed. Positioning of the elbow is not crucial, due to the use of high-quality reformats.

The patterns of articular fracture in the distal part of the humerus can be difficult to manage and therefore MDCT scans with MPR enhance preoperative assessment of the fracture and operative decisionmaking (Ring et al. 2003). In pediatric patients with immature skeletal systems, elbow fractures are often different types of Salter-Harris fractures, in which case MRI is the best imaging modality (Potter 2000, Griffith et al. 2001).

6.1.3 Shoulder

The anatomy of the glenohumeral joint is complex and in the case of fracture the components must be reconstructed if the kinetics of the joint are to be preserved (Poppen and Walker 1976, 1983). Due to the high incidence of humeral head avascular necrosis in displaced 3-part and 4-part fractures (Neer 1970, Tanner and Cofield 1983), it is essential that these fractures are treated adequately. Their treatment varies considerably, depending on the fragment displaced and the number of displaced fragments. For adequate treatment to be initiated, the extent of the fractures and the number and position of the dislocated fragments must first be correctly identified. The tubercular fracture fragments, especially from the lesser tubercle, and their displacements are often very difficult to assess in plain radiographs (Castagno et al. 1987), which was also seen in the present study. The sensitivity of conventional radiography in the detection of lesser tubercle fractures was poor, which may be due to the fact that AP internal and external rotation views were not generally used because they are usually difficult to obtain in cases of acute injury. The subscapularis tendon is inserted in the lesser tubercle and if the fracture is not well repositioned it will cause restricted internal rotation of the humerus.

Axial CT is the method of choice to aid in preoperative planning in difficult highly comminuted fractures of the proximal humerus (Castagno et al. 1987). In such patients the exact number of

fracture fragments is easily underestimated in radiographs, as was also seen in the present study. Compared with conventional helical CT, MDCT makes use of high-quality MPRs, which were useful in the present study in the coronal oblique and sagittal oblique planes to reveal the exact degree of fragment displacements. Therefore, MDCT with MPR increases the accuracy of fracture classification in comminuted proximal humerus fractures, thus aiding in surgical planning and decisionmaking.

The sensitivity of conventional radiography in the detection of bony Bankart lesions was good in this study. Fracture of the glenoid with a large fragment is known to cause anterior instability of the shoulder (Kummel 1970, Aston and Gregory 1973). The size of the bony Bankart lesion affects the degree of shoulder instability (Itoi et al. 2000) and if the osseous defect is large enough, Bankart repair with bone grafting is needed (Matsen and Thomas 1990, 1998). CT images are superior to plain radiographs in assessing the size of a bony defect in the glenoid (Itoi et al. 2003), as was also seen in the present study.

The origin of the fragment can be a diagnostic problem in radiography, as it was in 12 of our patients here. MPR in the coronal oblique and sagittal oblique planes shows the joint anatomy without interference from superimposed structures and the origin of the fragment is more easily revealed. MDCT also reveals occult fractures such as lesser tubercle, coracoid process, and scapular spine fractures, as shown in the present study.

6.1.4 Ankle and foot

Plain radiographs of the ankle are the mainstay for diagnosing ankle injuries (Greenspan 2000). The internal oblique view in addition to the AP and lateral projections increase the sensitivity of

conventional radiography in the detection of ankle fractures (Rogers 1992), but in patients with multitrauma and in those with severe comminuted ankle fractures, appropriate positioning of the ankle is difficult. In MDCT the position of the ankle is not crucial due to the high quality of the reformats used. The patterns of articular fracture in the distal part of the tibia, especially in comminuted pilon fractures, can be difficult to manage and therefore MDCT scans with MPR enhance the preoperative assessment of the fracture and operative decisionmaking. The occult posterior malleolus fracture can be potentially harmful and cause complications if not detected and accurately managed. Internal fixation of the posterior malleolus is recommended if the reduced fragment comprises more than one-fourth of the tibial articular surface (Griend et al. 1996).

Calcaneal fractures are the result of high-energy trauma, usually due to a fall from a height or to a motor vehicle accident (Sanders 2000), which was also seen in the present study. Conservative treatment is best reserved for nondisplaced calcaneal fractures. However, for patients who have displaced intraarticular fracture fragments, nonoperative treatment offers little chance of a return to normal function because a calcaneal malunion will develop (Sanders 1990, Darder Prats et al. 1993, Sanders 2000). In intraarticular calcaneal fractures the degree of depression of the posterior calcaneal facet may often be underestimated in lateral radiographs and also in coronal CT images (Rosenberg et al. 1987, Ebraheim et al. 1996). Nevertheless, MPR in the sagittal and coronal planes shows the exact position of the posterior facet and joint malalignment without interference from superimposed structures, thus aiding in decisionmaking between operative and nonoperative treatments.

Talar fractures are relatively rare (Adelaar 1989, Kuner et al. 1993), but in the present study they constituted 14% of all fractures. This was probably because our study population was composed of patients being treated at a level-one trauma center for injuries caused by high-energy trauma and

because patients with more simple foot injuries are treated based on plain radiographs and do not undergo MDCT. Subtalar joint dislocation is not a common injury (Bohay and Manoli 1996), but this finding was seen in 11% of all talus fractures in the present study; again, this unexpected finding is best explained by the large number of high-energy trauma patients in our study. Subtalar joint dislocations with associated intraarticular fractures involving the subtalar or talonavicular joints can lead to significant subtalar joint arthrosis (Delee and Curtis 1982). The overall sensitivity of conventional radiography in the detection of talar fractures is only moderate, and performing the diagnosis of associated intraarticular fractures of the subtalar or talonavicular joint with a subtalar joint dislocation is even more difficult in plain radiographs (Ebraheim et al. 1994), as was also seen in the present study. The presence of an intraarticular fracture exacerbates the prognosis (Bohay and Manoli 1996), and MDCT with MPR is a recommended complementary examination for revealing possible occult intraarticular fracture of the talus if subtalar joint dislocation or subluxation is suspected.

Lisfranc fracture-dislocation is related to high-energy direct or indirect trauma (Vuori and Aro 1993, Mantas and Burks 1994, Englanoff et al. 1995, Richter et al. 2001b). This was also seen in the present study, where the 2 main injury mechanisms were falling from high places and traffic accidents. Due to the high-energy injury mechanism, many patients also had additional foot and ankle fractures and severe injuries to other parts of the body. In a Lisfranc fracture-dislocation, the fracture lines and minimal tarsometatarsal malalignment are sometimes difficult to detect in conventional radiographs (Foster and Foster 1976, Norfray et al. 1981, Faciszewski et al. 1990, Lu et al. 1997, Preidler et al. 1999). It has been estimated that as many as 20% of Lisfranc joint injuries are missed on initial AP and oblique radiographs (Mantas and Burks 1994, Englanoff et al. 1995, Trevino and Kodros 1995). In the present study (IV,V) the number of false-negative radiographs was slightly higher, which may have been due to the patient population; weight-bearing images

cannot usually be obtained in multitrauma patients and appropriate positioning is also difficult in severe foot and ankle traumas. MPR provides better visualization of the complex fracture anatomy and even minimal joint malalignment in Lisfranc joints without interference by superimposed structures, thus aiding in surgical planning: the extent of the fractures and the dislocated joint facets are better evaluated in MPR than in radiographs, as shown in the present study.

Lisfranc fracture-dislocations may be easily overlooked in multitrauma patients if not clinically suspected, due to more obvious skeletal injuries and serious trauma in other body parts. Only after the patient begins weightbearing may this injury become symptomatic. MDCT and high-quality MPR rapidly provide accurate information on complex fracture morphology, which is important to ensure appropriate treatment and to avoid complications. Early diagnosis is crucial for proper management, to prevent poor functional outcome, and to minimize the possibility of posttraumatic arthrosis (Mantas and Burks 1994, Kuo et al. 2000, Richter et al. 2001b). In addition to occult Lisfranc joint fractures, MDCT also revealed occult and potentially damaging fractures in other parts of the foot and ankle such as talus, calcaneus, and navicular fractures.

Conventional radiography is in general only moderately sensitive in the detection of serious ankle and foot injuries. MDCT is an accurate and reliable imaging modality that is used in evaluating patients with ankle and foot traumas. MPRs are helpful in disclosing fracture patterns, particularly in complex ankle and foot fractures, where they enable comprehensive evaluation of fracture components and also reveal occult fractures. In the detection of midfoot fractures, the sensitivity of primary radiography was weak compared with MDCT. These fractures may be potentially damaging and cause complications if not detected and accurately managed.

Multitrauma patients known to have been exposed to high-energy trauma usually have multiple fractures and therefore the entire ankle and foot should be scanned if MDCT examination is planned. As shown in this study (IV,V), MDCT reveals occult fractures and shows the exact fracture anatomy in ankle and foot fractures, such as tibial pilon and complex calcaneal fractures and Lisfranc fracture-dislocations.

6.2 MDCT of the joint: role in emergency radiology

Radiography is commonly used as a primary imaging modality in acute joint trauma. However, based on the present study (I-V), it can be concluded that in high-energy multitrauma patients and in complex fracture patterns the overall sensitivity of plain radiographs is only moderate to poor. Therefore, in complex joint fracture patterns with equivocal radiographs, MDCT is recommended as a complementary examination. In these cases MDCT with MPR discloses the complex fracture morphology, reveals occult fractures, and shows the exact number of fracture components and their degree of displacement.

In high-energy multitrauma patients undergoing whole-body MDCT scanning, serious joint trauma could primarily be imaged in the same scanning session. This would save time and offer the possibility for a one-stop shop leading to fast, accurate and concurrent joint fracture and body trauma diagnosis in the same MDCT scanning session. Improved diagnostic accuracy bears a direct impact on patient care and surgical planning, eventually leading to improved care, quality of life, and decreased health care costs.

7. CONCLUSIONS

Based on Studies I to V, the following conclusions can be drawn:

1. MDCT is a valuable imaging method in acute wrist fractures in cases of equivocal primary radiographs and clinical suspicion of a fracture, where it can be used to confirm or rule out the presence of a fracture. It also detects occult fractures and shows the exact fracture anatomy in wrist fractures, thus increasing diagnostic accuracy and aiding in treatment planning.
2. MDCT is a valuable imaging method in acute elbow fractures, where it can be used to determine the extent of fractures in complex fracture patterns and to reveal the position or origin of dislocated fragments in cases of equivocal primary radiographs.
3. MDCT with coronal oblique and sagittal oblique reformats is a valuable imaging method in patients with acute, complex, proximal humerus fractures, where the extent of the fractures and the position, number, or origin of dislocated fragments is not clear in radiographs. In these cases MPR may increase the accuracy of fracture classification.
4. The overall sensitivity of radiography in the detection of foot and ankle fractures is only moderate to poor in patients with multiple injuries from high-energy trauma and in patients with complex fracture patterns. In these cases MDCT, whole ankle and foot scanned, is recommended for use as the primary imaging modality.

5. In high-energy multitrauma patients with foot and ankle trauma, MDCT with MPR can reveal occult Lisfranc fracture-dislocations, show the extent of the fracture-dislocation, and reveal occult fractures in other parts of the ankle and foot.

8. SUMMARY

The purpose of the present study was to assess the value of MDCT in the imaging of wrist, elbow, shoulder, ankle, and foot fractures compared with radiography in patients referred to a level-one trauma center.

I

Acute phase MDCT findings in wrist fractures compared with radiography were assessed. Patients with a wrist injury and who initially underwent MDCT were included. Imaging studies were retrospectively evaluated by injury mechanism, fracture location, and type. MDCT revealed 56 fractures and 7 dislocations in 29 patients, while in 9 patients (24%) MDCT was normal. Eleven patients (29%) underwent surgical procedures. The main injury mechanism was falling (58%). MDCT examination was not dependent on the wrist's position in the CT gantry due to the use of high-quality MPRs. Compared with radiography, MDCT detected occult fractures and ruled out suspected fractures, both mainly in the small carpal bones. High-quality MPRs gave significant information on the fracture anatomy. MDCT provides rapidly available and valuable information in assessing complex wrist fractures or when the primary radiography is equivocal.

II

The value of acute phase MDCT findings in elbow fractures compared with radiography was assessed. A total of 48 (86%) of the 56 patients had an elbow fracture and the total number of fractures was 65. Three main fracture types were established: 16 ulnar coronoid process fractures (25%), 13 radial head fractures (20%), and 12 humeral supracondylar fractures (18%). The 3 main injury mechanisms were falling in 38 patient (68%), falling from a height in 6 (11%), and traffic accidents in 5 (9%). In 6 patients (11%) MDCT revealed total of 13 occult fractures in the elbow

joint. Radial head fracture was the most common occult fracture (sensitivity of radiography 69%) in this study, constituting 31% of all occult elbow joint fractures. In 4 patients (7%) a displaced fracture fragment was detected in primary radiography, but the origin of the fragment was unclear. In all 4 cases MDCT revealed the origin of the fragment. In complex elbow fracture patterns the extent of the fractures and the position or origin of the dislocated fragments is shown in MDCT when radiography is equivocal.

III

MDCT findings in acute shoulder fractures compared with radiography in patients referred to a level-one trauma center were assessed. Three main injury mechanisms were established: falling in 113 patients (54%), traffic accidents in 36 (17%), and falling from a height in 12 (6%). Based on MDCT, a total of 311 fractures (152 in the scapula and 159 in the proximal humerus) occurred in 191 (91%) of 210 patients. The 2 most common radiographically occult fractures were lesser tubercle and coracoid process fractures. Thirty-five patients (17%) had a comminuted fracture of the proximal end of the humerus and in 20 (63%) of 32 patients (with radiographs available) the exact number of fracture fragments was underestimated in radiographs. In patients with complex proximal humerus fractures, in which the extent of the fractures and the position or origin of dislocated fragments is not clear in radiography, MDCT with MPR can reveal the exact fracture morphology. This may increase the accuracy of fracture classification and also reveal occult fractures in other parts of the shoulder.

IV

MDCT findings in acute ankle and foot fractures compared with radiography were assessed in patients referred to a level-one trauma center. MDCT and radiographs were retrospectively evaluated by fracture location, type, and injury mechanism, and primary radiographs of the ankle

and foot were compared with MDCT findings. A total of 517 fractures were found in 344 patients in all anatomical regions: ankle, calcaneus, talus, midfoot, and forefoot. The 3 most common occult fractures in the ankle not detected in primary radiography were isolated fractures of the posterior and medial malleolus and the Tillaux fracture. The calcaneus was the most commonly fractured bone and the sensitivity of radiography in calcaneal fractures was 87%. The sensitivity of radiography in talar fractures was 78%, while in the detection of midfoot fractures the sensitivity of radiography was only 25-33%. Lisfranc fracture-dislocations were not shown in primary radiography in 5 cases (24%) out of 21. The 3 main injury mechanisms were falling from a height in 164 patients (48%), a simple fall in 68 (20%), and a traffic accident in 47 patients (14%). In high-energy multitrauma patients and in complex ankle and foot fractures the sensitivity of radiography is only moderate to poor and in these cases MDCT is recommended for use as the primary imaging modality.

V

Acute phase MDCT findings in Lisfranc fracture-dislocations in multitrauma patients referred to a level-one trauma center were assessed. A total of 21 Lisfranc fracture-dislocations were found in 19 patients. Two main injury mechanisms were established: falling from a height in 10 cases (48%), and traffic accidents in 5 cases (24%). Primary radiographs were available in 17 cases (81%) and in 4 cases (24%) they were false-negative compared with MDCT. In all Lisfranc fracture-dislocations MDCT showed the joint anatomy and the extent of dislocation better than primary radiographs and in 6 cases (46%) out of 13 true-positive primary radiographs, MDCT revealed additional occult fractures in the Lisfranc joint and also in other parts of the foot and ankle in 6 (35%) of 17 cases. If primary radiography is equivocal, MDCT with MPR may reveal the extent of the fractures and even minimally dislocated joint facets in these complex injuries, thus aiding in treatment planning. In high-energy multitrauma patients with foot and ankle trauma, MDCT with MPR can reveal occult

Lisfranc fracture-dislocations, show the extent of the fracture-dislocations, and reveal occult fractures in other parts of the ankle and foot.

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