Eur Radiol (2002) 12:1728–1740
DOI 10.1007/s00330-001-1225-x

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Whole-body computed tomography in polytrauma: techniques and management

Received: 14 August 2001
Revised: 2 October 2001
Accepted: 15 October 2001
Published online: 13 December 2001

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Abstract An interdisciplinary team should be involved in the diagnosis and management of severely injured patients. The adoption of criteria for starting treatment for multiple trauma avoids underestimation of seriousness of injury. These criteria are established by the circumstances of the accident, the patterns of trauma, and the vital findings. Basic diagnosis comprises a limited number of plain films in the trauma room, including supine chest, lateral cervical spine, and pelvis, and ultrasound of abdomen, pleura, and pericardium. Organ diagnosis using CT is complementary and depends on the clinical findings and findings from the basic investigations. We recommend spiral CT (skull base 2/2/4 mm, cerebrum 8/8/8 mm native) and after intravenous contrast medium thoracic (5/7.5/5 mm) and abdominal CT (8/12/8 mm). Image reconstruction of bony structures can be added. The CT and the trauma center should be in close proximity; time-consuming transfers must be avoided. If this is not possible, a CT can be integrated in the trauma room. Our hospital trauma registry contains over 2200 entries. A quality committee has been established and external quality control is implemented.

Keywords Computed tomography · Spiral CT · Multiple trauma · Polytrauma · Emergency radiology · ATLS

Introduction

Computed tomography with its technical advances in the past decade has become increasingly valuable in the early clinical management of patients with multiple trauma. It is a sensitive and specific diagnostic tool in the early clinical process. Major technical developments have included the introduction of spiral CT in the early 1990s and its further development to multislice CT (MSCT) at the end of the decade, and these have contributed to its increasing importance.

A wide range of injuries can be diagnosed accurately with spiral CT [1, 2, 3, 4, 5, 6]. Its main advantages are speed, scanning of large body volumes, and fast image calculation, which result in lower risks for patients and allow combined CT studies of the head, thorax, abdomen, and pelvis. Computed tomography in the management of polytrauma, particularly in metastable patients [7, 8], has been shown to be beneficial.

In the past, the time factor limited the use of CT. At present, however, the use of fast spiral CT has a crucial role in the management of seriously injured patients. Fast spiral CT and MSCT protocols accelerate clinical processing and allow severely injured patients to have CT [7, 8, 9]. The higher speed of CT diagnosis comprises monitor reading of the studies and data net transfer of images to the trauma team in the admitting area, to an intensive care unit (ICU), or operating room (OR).

There have been a few reports about combined CT studies, so-called whole-body or head-to-toe protocols, and the logistic and strategic management of CT in patients with multiple injuries. They have early and extensive use of CT in common, but they differ substantially in detail.

Table 1 CT diagnosis in patients with multiple trauma whole-body CT protocols

Reference no. of patients	Body region	Scan variables [mm][a]	Contrast media[b]	Reading window	Comments
[10], *n*=27	Skull	5/7.5/5 spiral	–	Soft copy: brain, bone	Anteroposterior scanogram (2), 9 of 27 lateral scanogram
	Skull base	5/5 sequential	–		
	Thorax	10/20/5–10	Intravenous or none (see comment)	Lung	Intravenous contrast in 4 of 27 patients, 120 ml, 3 ml/s, delay 25 s
	Abdomen	10/20/5–10	Oral none	Soft	
[11], *n*=111	Spine	Not specified	–	C: 250 W: 1250	
	Skull	10/10/10	–	Not specified	Lateral scanogram
	Skull base	–	–	Not specified	
	Thorax	10/30/10	Intravenous 130 ml, 50 ml at 2 ml/s, and 70 ml at 0.5 ml/s	Not specified	Anteroposterior scanogram
	Abdomen	10/30/10	Oral non-specified Intravenous after thorax	Not specified	
[7], *n*=446	Skull	8/8/8	–	Brain, bone	Pre-programmed protocols, monitor reading Anteroposterior scanogram (1)
	Skull base	2/2/4 4 mm brain 2 mm bone	–	Brain, bone	Lateral scanogram
	Thorax	5/7.5/5	Intravenous 2 ml/kg body weight 2.5–3.5 ml/s, 25 s delay	Lung, soft, bone	
	Abdomen	8/12/8	60–70 s delay Oral 3% 500 ml	Soft, bone, lung	
	Spine	2/3/1–2	None	Soft, bone, spine	

[a] Slice thickness, table feed, image reconstruction increment
[b] Intravenous contrast medium volume (ml), flow rate (ml/s), scan delay (s), oral contrast medium

Low et al. reported on fast whole-body spiral CT in 27 severely injured patients using spiral CT as the primary diagnostic tool, adding digital CT scanograms to a single spiral-CT scan [10].

Leidner et al. described standardized non-helical CT protocols for head, body, and proximal extremities based on a study of 111 patients with blunt trauma whose circulation was stable [11]. The purpose was to achieve timely, efficient, and accurate radiological processing in a level-II European trauma center.

Our group developed protocols for pre-programmed semi-automatic spiral CT for studies of the head, thorax, and abdomen (RUSH-CT), and in 2000 we reported a consecutive series of 446 polytraumatized patients who had spiral CT embedded in interdisciplinary algorithms (Table 1) [7].

There is a general consensus in recent publications from major trauma hospitals that the use of spiral CT for the polytraumatized patient must be guided by the patient's clinical course. Computed tomography therefore needs to be integrated in standardized clinical guidelines for the early care of patients [9, 12, 13].

In this report we review the use of combined spiral-CT scans of patients with multiple injuries, we summarize recommended imaging protocols, and we present a strategic concept for the use of CT in early clinical management.

Incidence of multiple trauma in Europe

There is no central registry or generally accepted guidelines for the treatment of polytrauma, so there are no precise data on the incidence and outcome of multiple trauma in Europe. Table 2 shows main causes of fatal injuries in the European Union [14].

Germany has a central registry for multiple trauma established by the German society of trauma surgery ("Deutsche Gesellschaft für Unfallchirurgie," DGU), but not all hospitals report patients who match the polytrau-

Table 2 Causes of fatal injuries in the countries of the European Union in the years 1997 and 1998. Numbers are total of deaths/country. Most deaths (94% overall) were caused by traffic accidents, falls, and suicide [14]

	Traffic accidents	Falls	Intoxication	Suicide	Homicide	Total deaths
European Union 1997[a]	45,352	44,263	5028	45,952	3848	144,443
Germany 1998	7965	7229	269	11,644	708	27,815
Greece 1997	2408	376	298	374	167	3623
Spain 1998	6463	1784	1034	3261	355	12,897
France 1997	7904	9556	547	11,139	551	29,697
Ireland 1998	447	322	35	506	41	1351
Italy 1997	8059	10,529	315	4694	720	24,317
Luxembourg 1997	59	37	13	81	–	190
Netherlands 1998	1090	599	72	1519	176	3456
Austria 1998	917	973	91	1559	91	3631
Portugal 1997	2126	536	100	628	125	3515
Finland 1998	551	1190	560	1226	124	3651
United Kingdom 1998	3635	4605	1119	4389	415	14,163

[a] 15 EU countries (EU-15)

Table 3 Road deaths/million inhabitants in the countries of the European Union from 1990 to 1998 [14]

Country	1990	1996	1998	Change 1990/1998 (%)
Belgium	198	134	147	–26
Denmark	123	98	85	–31
Germany	139	107	95	–32
Greece	202	197	212	+5
Spain	232	140	151	–35
France	198	146	152	–23
Ireland	136	125	116	–15
Italy	126	116	110	–13
Luxembourg	186	171	143	–23
Netherlands	92	76	68	–26
Austria	202	127	119	–41
Portugal	305	275	243	–20
Finland	130	79	78	–40
Sweden	90	61	60	–33
United Kingdom	94	64	61	–35
European Union	155	117	114	–26

With the exception of Greece (+5%), there has been a significant reduction in the number of deaths caused by traffic in all countries. Best results were for Austria (–41%) and Finland (–40%) with a mean of –26% for the entire European Union

Table 4 Injuries causing 24,226 deaths [16]. Cerebral and hip and pelvic injuries accounted for almost 54% of all deaths

Injury	%	*N*
Total	100	24,226
Cerebral	31.2	7549
Hip and pelvic	22.5	5447
Spinal	5.1	1235
Thoracic	4.2	1018
Skeletal, others	3.5	849
Abdominal	3.0	723
Foreign bodies	3.4	825
Intoxication, drug abuse	2.9	706
Intoxication, others	4.6	1121
Burns	2.3	555
Drowning	2.3	559
Dismemberment	1.4	341
Suffocation	0.5	118
Not specified, others	13.1	3180

ma criteria to the registry. Past studies have estimated the number of individuals with multiple injuries at approximately 33,000/year based on 9485 people killed in traffic accidents in 1995 in Germany [15]. We therefore analyzed data for the road deaths in the European Union and the injuries that caused deaths (Tables 3, 4). The number of people killed in traffic accidents decreased in most European countries, but it still remains the leading cause of death up to the age of 45 years [14]. The main causes of death are cerebral and hip or pelvic injuries, whereas thoracic and abdominal injuries have fewer fatal outcomes [16].

These data may help to estimate the incidence of polytrauma in other European countries, although they are not entirely reliable. We encourage colleagues to publish their own data.

Management of CT diagnosis in early clinical care

Criteria for multiple trauma

The standard definition of polytrauma (two injured body regions of which one is potentially fatal) is not sufficiently objective [17]. Consequently, at our hospital we have developed filter criteria for starting treatment for polytrauma that involves consideration of the circumstances of the injury (Table 5) [13, 18, 19]. This obviates underestimation of seriously injured patients at reception in the emergency department. These criteria depend on the circumstances of the injury, the pattern of injuries, and the vital signs. They are linked to a mean probability of survival of 0.9, consequently to the death of 10%.

Interdisciplinary algorithm for early clinical care

The entire diagnostic and clinical process is conducted by an interdisciplinary algorithm (Table 6) [12, 20, 21]. This algorithm divides the early hospital care of a patient into four phases. Phase “Alpha” (within the first minute) is for basic measures of life support. During phase “Bravo” (<6 min) diagnosis and initiation of treatment of immediately life-threatening injuries, such as massive bleeding or tension pneumothorax, have to be completed. Phase “Charlie” (6–30 min) concentrates on the site and extent of the injuries and has specific checklists for all body regions. It is at this stage that patients undergo CT. Conventional radiological diagnosis is completed after the decision for the need for immediate operation in phase “Delta” (>30 min).

Radiological diagnosis is a central part of the initial clinical management phase and so has been incorporated in the procedural algorithms in the trauma center [13]. After introducing these algorithms, we observed a considerable improvement in the outcome of our patients. The mortality declined in patients with moderately severe injuries (injury severity score, ISS=18–24), severe (ISS: 25–49), and very severe (ISS: 50–75) injuries. For moderately severe injuries the decline was from 20% to 0 (p<0.05), for severe injuries from 24 to 8% (p<0.05), and for very severe injuries from 71 to 40% [21].

In another investigation conducted by a study group whose treatment deviated substantially from established algorithms, mortality from blunt abdominal trauma increased by a factor of 10 and from penetrating abdominal trauma by a factor of 3. Trauma centers have stated that deviations from established surgical schemes of treatment result in avoidable deaths in patients with multiple injuries in up to 3% of all cases and avoidable complications in up to 5% [22, 23, 24].

Table 5 Criteria for initiation of treatment in the emergency room. These people have a 90% chance of survival

Mechanism of injury
Traffic injury
– Pedestrian or cyclist hit by car
– High-speed car or motorcycle collision
– Car overturned
– Death of another passenger
– Ejection from the car
Fall
– Fall from a height >5 m
– Fall from unclear height
Explosion
Circumstances not known
Type of injury
Penetrating injury
– Missile injury
– Stab injury
Flail chest
Open thorax
Unstable pelvic fracture
Extremity fractures
– Fractures >1 long bone
– Proximal amputation
Multiple rib fractures plus other injuries
Vital signs
– Glasgow Coma Scale <10
– Systolic blood pressure <80 mmHg
– Respiration rate <10 or >29
– PO_2 <90% (<85% in those >75 years)

Quality assessment

Our own hospital trauma registry (Klinikum der Universität, LMU Munich) contains over 2200 entries and allows the analysis of the quality of management of severely injured patients. Statistically conspicuous trends are studied in detail and mortality meetings are held. Since 1993 the data have also been forwarded to the trauma registry of the DGU.

Basic diagnosis, radiological ABC

The initial investigation of all patients comprises digital plain films (chest, lateral cervical spine, and pelvis) and

Table 6 Phases of the early clinical and diagnostic management of patients with polytrauma. *OR* operation room; *ICU* intensive care unit

Phase [min]	Clinical management	Diagnostic management
Alpha (<1)	Life support	US: pleura; pericardium; abdomen
Bravo (<6)	Diagnosis and treatment of life-threatening injuries	Plainfilm radiographs: chest; lateral cervical spine; pelvis
Charlie (6–30)	Primary diagnosis, therapy (organ algorithm) Transfer to OR	CT: head; thorax; abdomen (<30 min)
Delta (>30)	Completion diagnosis, transfer to ICU or OR	Plain film: chest (control lines) US: abdomen (control <30 min) CT: additional scans (spine, coronal skull, extremities) Plain film: skeleton

ultrasound (abdomen, pleura, and pericardium). Such a concept is established in most major trauma centers and is essential to diagnose injuries that require immediate treatment such as tension pneumothorax, massive hemothorax, or massive abdominal bleeding. It is at this point that thoracic drainage tubes are inserted or thoracotomy or laparotomy is planned [8, 9, 12, 13].

In an attempt to standardize image evaluation and to integrate CT into the interdisciplinary treatment concept similar to the ABC rule (airway, breathing, circulation), a radiological ABC procedure with a similar orientation is used [13]. Standardization of the procedure reduces the time in the trauma center. The first plain-film radiographs of the thorax are available for patients with serious blunt trauma (ISS >15) at a mean of 7 min (SD 6 min) after admission to our clinic, compared with data from the DGU (n=1328 patients, 18 min, SD 23 min). The time until a CT of the head (CCT) is taken is 28 min (SD 12 min), compared with data from the DGU (n=573, 45 min, SD 28 min) [25].

Organ diagnosis

Organ diagnosis using CT is complementary and depends on the clinical findings and findings from the clinical and basic radiological diagnosis.

Some authors have suggested that polytrauma patients go directly for a CT scan and that the basic diagnosis be discarded [10, 11]. We think that this is not indicated, particularly for unstable high-risk patients, as immediate life-saving interventions or emergency operations may be delayed [9, 26].

Logistical concept

The CT scanner and the trauma center should be in immediate proximity to each other. Time-consuming transfers must be avoided. If this is not possible, a CT scanner can be integrated in the trauma room (see also mobile CT) [9, 27].

Prospective study on polytrauma

We performed an interdisciplinary study in which more than 2200 patients were documented prospectively. A registration form is filled out for all patients, which documents the course of treatment until rehabilitation. Among other things, it documents the Glasgow Coma Scale (GCS), the Injury Severity Score (ISS), the Revised Trauma Score (RTS), and the TRISS method (Trauma Score and the Injury Severity Score) to assess the probability of survival [28, 29, 30]. All diagnostic and therapeutic steps are recorded, including the occurrence and time of complications, and primary or secondary deaths up to 90 days.

Principles of CT diagnosis in polytrauma

Registration and positioning of the patient

Until the correct demographic data is not known, a consecutively numbered emergency registration ID is used for the radiology information system (RIS) and picture archive system (PACS). This eliminates delays to the workflow and image distribution.

Positioning aids are reliable in transporting patients to CT, the OR, or ICU. Boards with a U-shaped profile can adapt to the CT table [31]. The patient is moved head first onto the CT table; the skull tray is not used. The arms are carefully bent at the elbows and crossed fixed ventrally over the thorax. This reduces artefacts in the liver, spleen, and kidneys in dorsal CT image sections. Positioning of the arms above the head is not acceptable because it is time-consuming and may cause iatrogenic lesions of the shoulder or brachial plexus [13].

Monitoring cables, resuscitation tubes, and infusion lines exit at the foot end. Light-weight, portable monitors that can be positioned easily on the CT table together with the infusion pump are also useful.

Protocols

After the introduction of spiral CT, the early tendency was to run a single scan for thorax and abdomen, resulting in large pitch factors (2) and wide reconstruction intervals (10–15 mm) [10, 11]. More recently, dedicated CT organ protocols have largely been accepted [7, 8].

We first do a cranial spiral-CT scan (CCT) immediately followed by a thoracic and abdominal spiral scan. The initial images should be analyzed at the CT console parallel to the scanning process, findings are directly communicated to the head of the trauma team. After a joint meeting, a decision is made whether the patient should be moved directly to the OR or be transferred back to the trauma room or the ICU. An intracranial pressure (ICP) catheter insertion and other interventional procedures can still be performed in the CT suite [7]. Hardcopies help to avoid any delays in moving the patient despite the existence of a PACS.

Fast spiral CT

We developed a protocol for fast spiral CT (RUSH-CT) with the aim of making a complete CT examination within the first 30 min after admission to the hospital [7]. We include all urgent patients suspected of having cere-

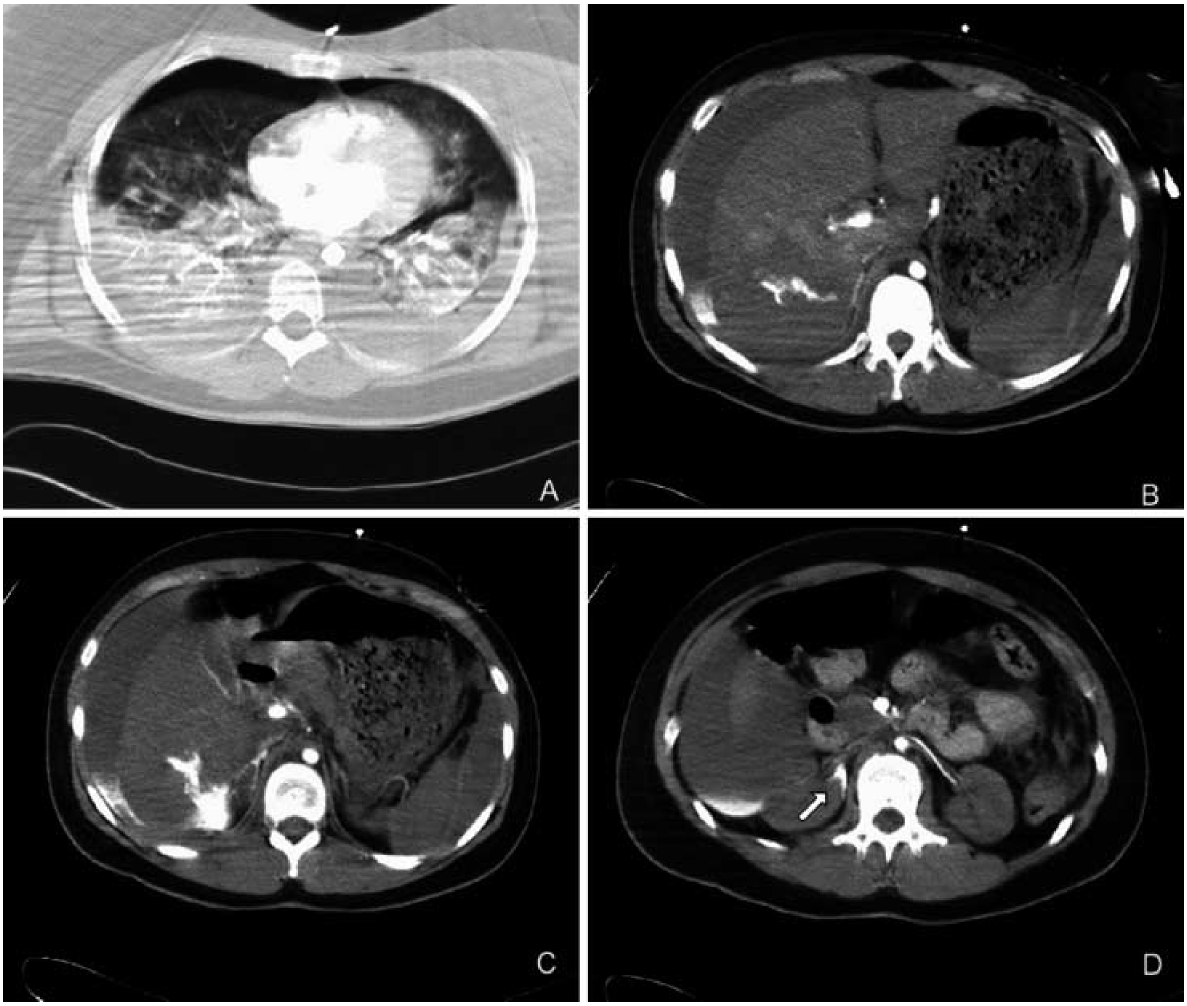

Fig. 1a–d Clinically urgent emergency patient with suspected multiple trauma was as a pedestrian involved in a car accident and underwent fast spiral CT. Combined injuries were detected. **a** Bilateral hematothorax with atelectasis, bilateral lung contusions and lung lacerations. A ventral pneumothorax was not detectable on the initial plain film of the chest. **b, c** A centrally located liver parenchyma laceration in the right liver lobe which extends to the liver capsule. There are at least two sites of contrast medium extravasation representing active arterial bleeding sites leading to a large subcapsular hematoma and intra-abdominal blood deserving immediate surgical therapy. **d** An additional dorsal subcapsular bleeding of the right kidney (*arrow*). Note the small diameter of the abdominal aorta as a sign for centralization of the circulation and shock

bral or thoracic trauma and trauma as a result of high-speed motor vehicle crashes. It is also used when the circumstances of the injury are uncertain, if there is a conspicuous discrepancy between clinical findings (respiratory and circulatory function) and the identifiable injuries. Metastable patients who have been resuscitated are also classified as urgent if they had an initial episode of unstable cardiovascular function [20, 21].

Various studies have shown the need for completing CT diagnosis within the first 60 min after admission. Introduction of the RUSH-CT with pre-programmed protocols, simultaneous image reconstruction, and monitor reading further shortened the overall examination time in CT from 35 to 15 min for a CCT, CT of the thorax, and CT of the abdomen (Fig. 1) [7].

Radiological follow-up

After completing all CT scans, the patient is moved back to the trauma center. If necessary, the skeletal radiograms can be completed there. These plain films should by no means be taken first as they would delay the CT diagnosis and possibly immediate life-saving operations. At this stage, at the latest after 30 min, a control sonogram is obtained to assess secondary onset of abdominal bleeding or the dynamics of previously diagnosed hemorrhages in the thorax and abdomen [9, 12].

If the chest is injured, in particular after insertion of chest tubes, intubation, or insertion of a central venous catheter, a control radiogram of the thorax should be taken [13].

CT diagnosis of cerebral trauma

The sooner treatment is started the better the prognosis of patients with serious cerebral trauma. In the early clinical management, a CCT is the most important diagnostic measure and has to be completed within the first 30 min [32, 33].

Protocols

The CT examination is run native; slice thickness is 3–4 mm (skull base) and 5–8 mm (supratentorial section). A spiral CT is recommended for the infratentorial section with slice thicknesses of 3–4 mm for the parenchyma evaluation and 1–2 mm for the assessment of the bony structures. Both can be obtained from a single set of data. Depending on the manufacturer, the use of volume artifact reduction technology is useful in this context [34]. Spiral-CT technology is used for supratentorial examination as an alternative to sequential scans; the latter have the advantage of better differentiation of gray and white matter and less likelihood of bony artefacts. Recent studies have shown that this has no major impact on the diagnosis of traumatic alterations [35]. We also recommend that the bodies of the first and second cervical vertebrae be included in examinations of the skull base for patients with multiple injuries [9]. Intravenous contrast media is used only in selected cases, such as to rule out an isodense hematoma [33].

Problems arise in diagnosis primarily as a result of misregistration and artifacts, in particular the differentiation of bleedings at the skull base and near the surface of the cranium. Supplementary scans can be done, if necessary in thinner slices and with different angulation. If findings remain equivocal, additional MRI can be required.

Indications

A CCT is always performed if the patient is disorientated, or has a focal neurological deficit, or GCS <15. Another indication is if a reliable neurological assessment is not possible because the patient is intoxicated or has been intubated. A CCT is also mandatory if there are external signs of injury to the neurocranium or to the face, or if cervical spine injuries are suspected [32, 33].

Film reading and image reconstruction

All scans are read in the bony and brain parenchymal windows. Viewing the soft tissue window is useful for assessing orbital structures and the soft parts of the face. The bony window should be reconstructed later from the raw data set, again in a high-resolution kernel in 1–2 mm. In all cases the lateral scanogram should be studied enlarged as many fractures can be identified, particularly their possible crossing of the medial meningeal artery or of a venous sinus.

Additional considerations

Magnetic resonance imaging is indicated if spinal trauma, brain stem lesions, or shearing injuries are suspected that cannot be identified on CT. An MRI may also be required to rule out bleeding close to the skull base and brain stem [32, 33]. Numerous other indications arise later [33, 36].

CT diagnosis of thoracic trauma

If a thoracic trauma is not identified at an early stage, the prognosis of a patient with multiple trauma is substantially compromised.

Protocols

The spiral technique is used for thoracic CT. A slice thickness of 4–5 mm at a pitch of 1.5 (5/7.5/5 mm) is useful to evaluate the lung parenchyma. When the findings are equivocal the vascular mediastinal structures can be reconstructed with a slice thickness of 2 mm. This data set can also be used for multiplanar (MPR) or three-dimensional (3D) image reconstructions. The area examined should include the body of the seventh cervical vertebra and the basal pulmonary segments.

The injection of contrast media is essential. Adults are given a bolus of 2 ml/kg body weight with an injection rate of 2.5–3.5 ml/s and a delay of 25 s for peripheral venous injections or 15 s for central venous injection. In older or metastable patients with impaired circulation time these values should be increased by 30% [7, 8].

We prefer a caudal-cranial scan direction, as at 35-s scan time and a scan delay of 25 s the injection of contrast medium is already complete when the thoracic inlet is reached (140 ml at 3 ml/s=47 s). This reduces artifacts from in-flowing contrast medium and the aorta and the supra-aortic vessels are maximally enhanced. If possible, the scans should be obtained while the patients hold their breath or if tolerable the ventilator is kept in inspiration in order to reduce motion artifacts.

Indications

A thoracic CT should always be acquired if consolidations, contusions, or indirect signs of pneumothorax are

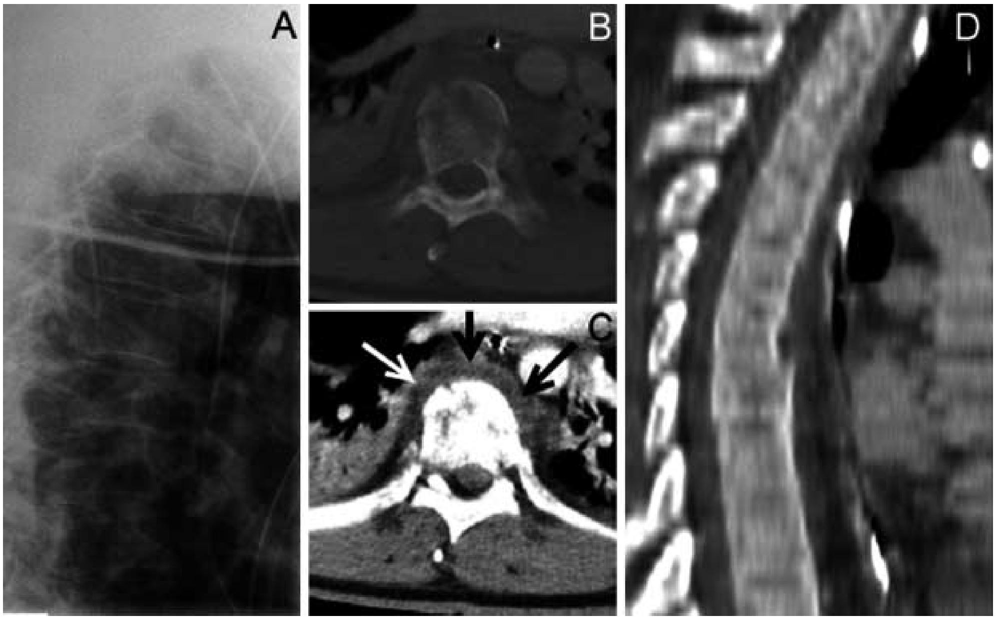

Fig. 2a–d A complex unstable fracture of the eleventh thoracic vertebral body. **a** A lateral plain film was taken in the trauma room. A fracture could not be detected. **b**, **c** The regular axial spiral-CT scan of the thorax reliably demonstrates a complex fracture with involvement of the trailing edge (*arrow* in **c**). **d** The soft tissue window demonstrates a paravertebral bleeding. The sagittal multiplanar reconstruction (MPR) was processed from the regular thoracic spiral-scan data set. The fractured vertebral body can be easily depicted with no relevant narrowing of the spinal canal

detected on the plain radiograms, and if there are fractures of the thoracic spine, the scapula, or of more than three ribs or the first or second rib. It is also indicated if the definition of the diaphragm is indistinct or if an injury to the mediastinal vessels, bronchi, or trachea is suspected.

A CT of the thorax is also indicated by clinical findings such as blood from the tracheal tube, air from the thoracic drain, or if subcutaneous emphysema is clinically or radiologically evident. It should also be done if there are contusions on the chest wall, the thorax is unstable, or if intubation was necessary because of clinical deterioration [8, 13, 37]. As external evidence is seen in only approximately half of all thoracic injuries, the mechanism of the accident alone or the medical history should lead to the assumption that a thoracic injury has been sustained even if the chest radiograph is normal. A CT angiography (CTA) of the thorax should also be done if a vascular lesion is suspected, in particular in deceleration injuries, e.g., high-speed car crashes, or if radiological or sonographic images point to a possible injury of the aorta [4].

Film reading and image reconstruction

Images are read in the lung parenchyma, soft tissue, and bone windows. Fractures of the thoracic spine are identifiable with sufficient diagnostic certainty on regular CT thoracic scans. A conventional plain film of the thoracic spine may then be unnecessary. In doubtful cases, images should be reconstructed from the data set with 2- to 3-mm increments in the bone algorithm and multiplanar reconstructions prepared (Fig. 2) [38, 39].

Additional diagnostic considerations

Supplementary MRI examinations are necessary if injury of the diaphragm cannot be ruled out with certainty by multiplanar CT, or if a spinal contusion is suspected [40]. A multiplanar or 3D reconstruction of the vessels can be done by CT angiography to show aortic injury [4, 41]. In this case, the origin of the supra-aortic vessels should be included. According to recent reports, the sensitivity of spiral CT is superior to that of digital subtraction angiography (DSA) [41, 42, 43, 44]. Digital subtraction angiography is only indicated for equivocal findings or to determine the extent of aortic injury. If the CT shows no injury, no further examination is necessary [8].

CT diagnosis of abdominal trauma

Protocol

Spiral CT of the abdomen should be done after intravenous injection of contrast medium with a delay of 60–70 s. In this case, the contrast medium bolus for thoracic CT can be used for the abdominal CT with a 25-s delay after approximately 25-s scan time. The slice thickness is 6–8 mm at a pitch of 1.5 (8/12/8 mm). If the findings are equivocal, a reconstruction interval of 5 mm can be selected [7, 8].

Oral contrast medium (3%, 500–750 ml/5–40 min) can be considered in less urgent patients; it has been proven to be beneficial in diagnosis of mesentery and small bowel injuries. But scanning of urgent multiple-trauma patients should not be delayed [45].

The administration of rectal contrast medium is usually not done. It may, however, be helpful to answer specific questions when there is a suspicion of a lesion of the rectum or colon. We use this technique only as a later examination [46].

In patients with abdominal injuries, an additional scan should be performed in the urographic phase. This makes an assessment of the urinary system possible. This examination is generally done 3–5 min after the injection of the contrast medium. A double injection of contrast medium has been tested in several studies but proved to be inferior to the single bolus injection in combined examinations [47].

Indications

An abdominal CT is indicated when there is sonographic evidence of free intra-abdominal fluid or organ lesions or retroperitoneal bleeding, but no indication for immediate surgery. An abdominal CT is also recommended if the sonographic image quality is poor, if the findings are equivocal, and if there is a discrepancy between the clinical progress and negative sonographic findings. It is also called for if there are pelvic or vertebral fractures or contusion marks on the skin, and if there is a suspicion of a pelvic or proximal femoral fracture or if an abdominal injury seems plausible in patients with multiple injuries [9, 13, 48, 49].

Film reading and image reconstruction

All images are observed in the soft tissue, bone, and also lung parenchyma windows; the latter provides sensitive proof of free intra-abdominal air.

Whether it is possible to obtain sufficiently sensitive proof of spinal and pelvic fractures by analyzing the abdominal or thoracic CT scan in the bone window is currently the subject of several studies. In our experience it is possible to dispense with conventional images of the lumbar spine and pelvis [38, 39].

Additional diagnostic considerations

For complex pelvic fractures with extensive retroperitoneal bleeding a CT, possibly with retrograde filling of the bladder with intravenous contrast media, is done to rule out a rupture of the bladder [50, 51].

CT diagnosis of spinal trauma

Protocols

The cervical spine is examined in spiral mode with overlapping reconstruction (3/4.5/2 mm) and the slice thickness should not exceed 2–3 mm. At the occipitocervical junction, high-resolution slices may be required (<1 mm).

We image the thoracic and lumbar spine as part of the thoracic and abdominal spiral scans. Fractures of the thoracic and lumbar spine are reliably detected by whole-body spiral CT, which is more reliable than plain films (Fig. 2) [39].

Indications

A disrupted posterior line of a vertebral body, widening of the vertebral canal or facet joints, a wide interlaminar space, and displacement of vertebral bodies are absolute indications for CT. Fuzzy paravertebral soft tissue contour, indicative of bleeding from fractured vertebrae, is also an indication. Patients with appreciable cerebral trauma should have beside CCT a CT of the cervical spine [33, 50, 52].

Film reading and image reconstruction

Imaging of the bony kernel provides sensitive proof of thin fracture lines. If MPR or 3D display is desired, a soft tissue kernel calculation must be performed. The film reading is in the bone and soft tissue windows and in an adapted brain parenchyma window to show spinal bleeding.

Multislice CT

The introduction of multislice CT (MSCT) is a major development. It promises a remarkable reduction in scanning time and motion artifacts, and improved imaging of pathological structures and heart and major arteries. With almost isotropic voxels and therefore improved z-axis resolution, it also allows improved MPR and 3D reconstructions [53].

To date, there are no specific reports concerning MSCT in multiple trauma, but initial results have already been presented [54]. Further reports of its use in emergency radiology are expected. Obviously, accelerated acquisition of data, reduced motion artifacts, and better image reconstruction help to improve the diagnosis of the multiply-injured patient. The introduction of four or more detector rows will have definite impact on the established imaging techniques and algorithms.

We recommend using arterial-phase scanning for the thorax and parenchymal phase for the abdomen. Depending on the manufacturer, a collimation of 4×2.5–3.75 mm or 4×5.0 mm is suitable with wider slices for low-contrast (parenchymal organs) and narrow slices for high-contrast objects (bone).

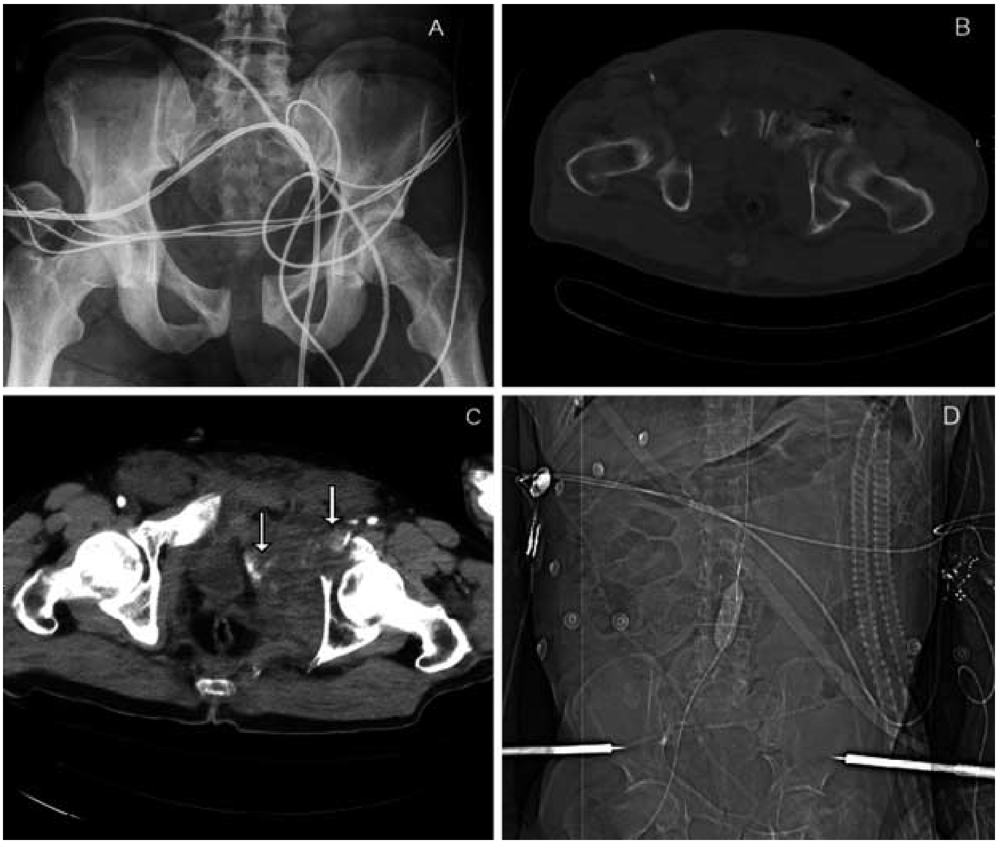

Fig. 3a–d Multiple-trauma patient involved in motor vehicle accident. **a** An open-book fracture of the pelvis with a disruption of the symphysis and the right ileosacral joint. **b** The spiral-CT scan confirms an additional fracture of the left acetabulum. **c** The soft tissue window detects a massive active bleeding from branches of both the external and internal iliac arteries (*arrows*). After the patient became unstable in the CT room, a balloon occlusion catheter was inserted under CT guidance via the right femoral artery to prevent further bleeding from the left arteries. **d** An anteroposterior scanogram confirms the infrarenal position of an inflated 20-mm balloon occlusion catheter in the abdominal aorta. After an additional pelvic clamp was mounted to stabilize the pelvic fractures, the patient was transferred to the operating room

Mobile CT

If the architecture of the hospital does not allow rapid transfer of patients to the CT suite, mobile CT scanners may be integrated in the trauma room [55, 56].

With as little as 50 m between rooms on the same level, there is a mean of 15 min lost between the trauma center diagnosis and CT diagnosis, which is doubled if the patient is moved again. Between three and seven changes of position may be necessary on the way to the OR or ICU [57].

A possible alternative to consider is a mobile CT (Tomoscan M, Philips, Eindhoven, The Netherlands) that can be operated at any time at any place. "Plug and play" at 220 V eliminates the need for pre-installations. Three separate mobile components (gantry, table, and console) make it unnecessary to reposition the patient during transport. Sequential studies, spiral CT, and multiplanar reconstruction options are possible for all standard questions. The image quality is lower than that which can be achieved with dedicated SCT or MSCT scanners but is comparable with displays of other CT providers in this market segment.

The major limitation of this equipment is the limited battery and tube capacity, resulting in limited scan volumes (sequential mode 600 mm, spiral 35 rotations), which necessitates up to three spiral scans of the body and therefore prolonged acquisition time.

Protocols

We recommend the combined sequential examination of the neurocranium (3/3 mm skull base, 7/7 mm supratentorial), cervical spine (2/2 mm), and entire thorax and abdomen (10/10 mm). With a 2-s rotation time the total scanning time is 10–14 min.

Mobile CT has been compared with thoracic plain films and abdominal sonography for hemodynamically stable, polytraumatized patients. Acute injuries relevant to treatment were detected in the thorax in approximately 30% of all patients, and in the abdomen in up to 41%. There were no false-negative CT scans in these studies [58, 59].

We conclude that mobile CT can be considered as alternative in the trauma room if a spiral CT is not available in the immediate proximity.

Interventional procedures in the CT suite

We recommend to furnish the CT suite with complete anesthesia equipment and operating room lights allowing save diagnosis and early interventional procedures.

Aortic balloon occlusion

If there is massive bleeding in the pelvis or in the retroperitoneum, or laceration of the proximal femoral vessels, or penetrating abdominal trauma in a patient who is not yet fit for laparotomy, a balloon occlusion of the aorta may be undertaken in the CT room [60, 61]. A 20-mm diameter balloon catheter is introduced through the femoral artery. The catheter is placed below the renal arteries and above the aortic bifurcation and its situation is checked by a CT scanogram (Fig. 3).

Intracranial pressure catheter

The CT suite is equipped for minor operations. Placement of an intracranial pressure (ICP) catheter is possible by CT guidance; CT fluoroscopy guidance has recently been used [62].

The patient is moved head first onto the CT table by the gantry and the operating area on the skull is prepared. An in-room monitor gives the operating surgeon the option of an intermittent CT-guided ventricular drainage system.

Chest tubes and central lines

Thoracic drains and central vein catheters can be inserted and their position and function can be checked by CT scans [13].

Pelvic clamp

In cases of unstable pelvic fractures it is possible to apply a pelvic clamp in the CT suite before the patient is transferred. We have combined this technique with the introduction of a balloon occlusion catheter in unstable patients (Fig. 3).

Conclusion

The use of whole-body spiral CT for people who have sustained multiple injuries has had a major impact on the early phase of treatment. Life-threatening injuries can be detected with good sensitivity and specificity.

Guidelines for the use of CT are essential, and these should depend on the patient's clinical findings. The development of interdisciplinary algorithms for treatment in trauma centers has proved to be useful. The radiologist must be integrated as an active member of the trauma team and participate in diagnostic and therapeutic decisions.

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