OULU 2010
D 1048

ACTA UNIVERSITATIS OULUENSIS

Lauri Ahvenjärvi

COMPUTED TOMOGRAPHY IN DIAGNOSTICS AND TREATMENT DECISIONS CONCERNING MULTIPLE TRAUMA AND CRITICALLY ILL PATIENTS

FACULTY OF MEDICINE,
INSTITUTE OF DIAGNOSTICS, DEPARTMENT OF DIAGNOSTIC RADIOLOGY,
INSTITUTE OF CLINICAL MEDICINE, DEPARTMENT OF ANAESTHESIOLOGY,
DIVISION OF INTENSIVE CARE,
UNIVERSITY OF OULU;
DEPARTMENT OF INFECTION CONTROL, OULU UNIVERSITY HOSPITAL

ACTA UNIVERSITATIS OULUENSIS
D Medica 1048

LAURI AHVENJÄRVI

COMPUTED TOMOGRAPHY IN DIAGNOSTICS AND TREATMENT DECISIONS CONCERNING MULTIPLE TRAUMA AND CRITICALLY ILL PATIENTS

Academic dissertation to be presented with the assent of the Faculty of Medicine of the University of Oulu for public defence in Auditorium 7 of Oulu University Hospital, on 16 April 2010, at 12 noon

UNIVERSITY OF OULU, OULU 2010

Copyright © 2010
Acta Univ. Oul. D 1048, 2010

Supervised by
Professor Tero Ala-Kokko
Professor Osmo Tervonen
Docent Hannu Syrjälä

Reviewed by
Docent Erkki Kentala
Docent Seppo Koskinen

ISBN 978-951-42-6148-0 (Paperback)
ISBN 978-951-42-6149-7 (PDF)
http://herkules.oulu.fi/isbn9789514261497/
ISSN 0355-3221 (Printed)
ISSN 1796-2234 (Online)
http://herkules.oulu.fi/issn03553221/

Cover design
Raimo Ahonen

JUVENES PRINT
TAMPERE 2010

Ahvenjärvi, Lauri, Computed tomography in diagnostics and treatment decisions concerning multiple trauma and critically ill patients.
Faculty of Medicine, Institute of Diagnostics, Department of Diagnostic Radiology, Institute of Clinical Medicine, Department of Anaesthesiology, Division of Intensive Care, University of Oulu, P.O.Box 5000, FI-90014 University of Oulu, Finland; Department of Infection Control, Oulu University Hospital, P.O. Box 22, FI-90029 OYS, Finland
Acta Univ. Oul. D 1048, 2010

Abstract

Technical improvements in computed tomography (CT) scanners have provided new possibilities to exploit the resources of this imaging modality in the evaluation of patients with multiple injuries or patients being treated in an intensive care unit (ICU). The purpose of this study was to assess the significance of multi-detector computed tomography (MDCT) in diagnostics and treatment decisions concerning multiple trauma and critically ill patients.

Findings of MDCT using a dedicated trauma protocol in 133 patients exposed to high-energy blunt trauma were retrospectively evaluated. Diagnostic information about the injuries that would enable planning of treatment was sought. The imaging protocol consisted of axial scanning of the head and helical scanning of the facial bones, cervical spine, thorax, abdomen, and pelvis. Ninety-nine of the patients (74%) had at least one finding consistent with trauma. Nineteen false negative findings and two false positive findings were made. The overall sensitivity of MDCT was 94%, specificity 100%, and accuracy 97%.

The reliability of a structured 5-min evaluation of MDCT images from the scanner’s console was prospectively evaluated in 40 high-energy trauma patients. The dedicated trauma protocol covering the thorax, abdomen, and pelvis was used in MDCT scanning. The findings were compared with the final radiological diagnosis of the MDCT data made on a picture archiving and communicating system (PACS) workstation, the operative findings, and the clinical follow-up. The evaluation from the scanner’s console enabled diagnosis of all potentially life-threatening injuries, the sensitivity for all injuries being 60% and specificity 98%.

The effects of MDCT on the treatment of patients in a 12-bed medical-surgical ICU were observed prospectively. Sixty-four patients with an ICU stay longer than 48 h had had inconclusive findings with other modalities of radiological imaging. They underwent altogether 82 MDCT examinations. Fifty examinations (61%) resulted in a change in treatment, and 20 (24%) of them otherwise contributed to or supported clinical decision-making. Twelve examinations (15%) failed to provide any additional information relevant to the patient’s treatment. MDCT examination was helpful in general ICU patients, with inconclusive findings with other imaging modalities.

CT images of 127 mixed medical-surgical ICU patients were retrospectively reviewed for the previously determined findings. Forty-three of these patients underwent open cholecystectomy, revealing eight cases with a normal gallbladder (GB), 26 with an edematous GB, and nine with necrotic acute acalculous cholecystitis (AAC). Abnormal CT findings were present in 96% of all the ICU patients. Higher bile density in the GB body and subserosal edema were associated with an edematous GB. The most specific findings predicting necrotic AAC were gas in the GB wall or lumen, lack of GB wall enhancement, and edema around the GB. The frequent prevalence of nonspecific abnormal imaging findings in the GB of ICU patients limits the diagnostic value of CT scanning.

Keywords: acalculous cholecystitis, computed tomography, decision-making, intensive care, multiple trauma

To my family

Acknowledgements

This study was carried out during the years 2003–2010 at the Department of Diagnostic Radiology, Oulu University Hospital, in collaboration with the Department of Anaesthesiology, Division of Intensive Care, and the Department of Infection Control, Oulu University Hospital.

I owe my deepest gratitude to my supervisor, Professor Osmo Tervonen, M.D., Head of the Department of Diagnostic Radiology, for his encouragement and support during this work. He provided the opportunity, excellent research facilities, and positive atmosphere for accomplishing this work.

I express my greatest gratitude to my other supervisors, Professor Tero Ala-Kokko, M.D., Department of Anaesthesiology, Division of Intensive Care, and Docent Hannu Syrjälä, M.D., Head of the Department of Infection Control, for their constant support, guidance, and endless encouragement during all these years. I have had a fascinating opportunity to work with them in the field of intensive care medicine. Their expertise and intransigent attitude towards patient care is admirable.

I am grateful to the reviewers of this thesis, Docent Erkki Kentala, M.D., and Docent Seppo Koskinen, M.D., for their thorough review of the manuscript and constructive criticism and advice. I am also grateful to authorized translator Keith Kosola for the careful revision of the language of this thesis.

I wish to sincerely thank all my collaborators. It has been a great pleasure to work with a group of specialists and enthusiastic people, including Docent Juha Saarnio, M.D.; Docent Jouko Laurila, M.D.; Docent Vesa Koivukangas, M.D.; Docent Risto Ojala, M.D.; Airi Jartti, M.D., Ph.D.; Jaakko Niinimäki, M.D., Ph.D.; Pekka Ylipalosaari, M.D., Ph.D.; Jarkko Halonen, M.D.; Lauri Mattila, M.D.; and Pasi Ohtonen, M.Sc. This study would not have been accomplished without their contribution.

I am thankful to Marianne Haapea, M.Sc, for her assistance in statistical issues. I thank Mr. Kari Kylmäniemi and study nurses Maarit Finnberg, Tarja Lamberg, and Sinikka Sälkiö for helping me with data collection. I also wish to thank Mrs. Leila Salo and Ms. Arja Väisänen for their kind assistance in practical matters.

I express my gratitude to Docent Eija Pääkkö, M.D., for her favorable attitude towards scientific work. Docent Eero Ilkko, M.D., and Juha Koskenkari, M.D., Ph.D, deserve my warmest gratitude for forming such a supportive follow-up group for this thesis. I am sincerely grateful to Professor Seppo Lähde, M.D., who introduced me to the field of radiological challenges in intensive care patients and for his excellent teaching.

I wish to thank all my colleagues at the Radiology Departments of Oulu University Hospital; especially in the team of body radiology. It has been a great pleasure to work with you.

Finally, I wish to express my dearest thanks to my wife, Tarja for her unyielding understanding and patience during all these years. You love has encouraged me and brightened the days of agony of this work. I am also deeply grateful to our beloved children Henrik, Valtteri, Aleksi, Joonatan, and Janika. Your sincere joy about little matters in everyday life reminds me about the most essential things in life.

This study was financially supported by grants from the Radiological Society of Finland, the Arno Hollmén Foundation, and the Finnish Medical Foundation, all of which are gratefully acknowledged.

Abbreviations

AAC	acute acalculous cholecystitis
AAST	American Association for the Surgery of Trauma
APACHE II	acute physiology and chronic health evaluation score
BCVI	blunt cerebrovascular injury
CEUS	contrast-enhanced ultrasonography
CT	computed tomography
CTPA	computed tomography pulmonary angiography
CXR	chest radiograph
EAST	Eastern Association for the Surgery of Trauma
FAST	focused assessment with sonography for trauma
GB	gall bladder
GCS	Glasgow coma scale score
ICU	intensive care unit
ISS	injury severity score
MDCT	multi-detector computed tomography
MRI	magnetic resonance imaging
NEXUS	National Emergency X-radiography Utilization Study
NPV	negative predictive value
OPTX	occult pneumothorax
PACS	picture archiving and communicating system
PEEP	positive end-expiratory pressure
RTIR	real-time image reconstruction
SAPS II	simplified acute physiology score
Se	sensitivity
Sp	specificity
SOFA	sequential organ failure assessment score
VAP	ventilator-associated pneumonia

List of original publications

This thesis is based on the following original articles, which are referred to in the text by their Roman numerals.

I Ahvenjärvi L, Mattila L, Ojala R & Tervonen O (2005) Value of multidetector computed tomography in assessing blunt multitrauma patients. Acta Radiol 46(2): 177–183.

II Ahvenjärvi L, Niinimäki J, Halonen J, Tervonen O & Ojala R (2007) Reliability of the evaluation of multidetector computed tomography images from the scanner's console in high-energy blunt-trauma patients. Acta Radiol 48(1): 64–70.

III Ahvenjärvi LK, Laurila JJ, Jartti A, Ylipalosaari P, Ala-Kokko TI & Syrjälä HP (2008) Multi-detector computed tomography in critically ill patients. Acta Anaesthesiol Scand 52(4): 547–552.

IV Ahvenjärvi L, Koivukangas V, Jartti A, Ohtonen P, Saarnio J, Syrjälä H, Laurila J & Ala-Kokko T (2010) Diagnostic Accuracy of Computed Tomography Imaging of Surgically Treated Acute Acalculous Cholecystitis in Critically Ill Patients. J Trauma, in press.

Contents

Abstract
Acknowledgements 7
Abbreviations 9
List of original publications 11
Contents 13
1 Introduction 15
2 Review of the literature 17
2.1 Multiple blunt trauma 17
2.1.1 Trauma-related death 17
2.1.2 Radiological imaging approach for trauma patients 17
2.2 Critically ill patients 18
2.3 Computed tomography 18
2.3.1 Technical development 18
2.3.2 Advantages 19
2.3.3 Disadvantages 19
2.3.4 CT radiation dose 21
2.4 Computed tomography in blunt multiple traumas 21
2.4.1 Craniocerebral and facial injury 21
2.4.2 Spinal trauma 22
2.4.3 Thoracic trauma 24
2.4.4 Abdominal trauma 26
2.4.5 Retroperitoneal trauma 29
2.5 Computed tomography in critically ill patients 31
2.5.1 Thoracic imaging 31
2.5.2 Abdominal imaging 33
2.6 Other imaging modalities 34
2.6.1 Plain films 34
2.6.2 Sonography 35
2.6.3 Magnetic resonance imaging 36
2.7 Radiologists as part of a multidisciplinary team 37
2.8 Statistical measures 37
3 Purpose of the study 39
4 Patients and methods 41
4.1 Study population 41
4.2 Main outcome variables and parameters 42

4.3 Imaging methods ... 44
4.3.1 Multiple blunt trauma patients (studies I and II) ... 44
4.3.2 Intensive care unit patients (studies III and IV) ... 44
4.4 Image assessment ... 45
4.5 Statistical analysis ... 46
5 Results 47
5.1 Main clinical results (I–IV) ... 47
5.2 Accuracy of computed tomography in multiple trauma diagnostics (I) ... 47
5.3 Reliability of computed tomography in rapid screening of multiple traumas (II) ... 50
5.4 Effect of computed tomography on the treatment of ICU patients (III) ... 51
5.5 Accuracy of computed tomography on AAC (IV) ... 53
6 Discussion 57
6.1 General aspects of the study ... 57
6.2 Strengths and weaknesses ... 57
6.3 Accuracy of CT in assessing blunt multiple trauma patients ... 58
6.4 Evaluation of CT images from the scanner's console ... 60
6.5 Impact of CT on clinical decision-making in critically ill patients ... 61
6.6 CT findings in acalculous cholecystitis in critically ill patients ... 63
6.7 Generalization of the results ... 66
6.8 Clinical impacts of the study ... 66
6.9 Future aspects ... 67
7 Conclusions 69
References 71
Appendix 91
Original publications 93

1 Introduction

Major trauma is a leading cause of death worldwide, with road traffic accidents alone causing 1.3 million deaths annually (Soreide 2009). There were 1189 trauma-related deaths in the 15–64-year-old age group in Finland in 2007 (Tilastokeskus). The estimated number of seriously injured patients in Finland is approximately 1000–1300 patients a year (Handolin *et al.* 2006). Clinical findings may remain equivocal or misleading in 20–50% of blunt multiple trauma victims (Houshian *et al.* 2002, Schurink *et al.* 1997). Hence, there is a demand for a rapid and reliable imaging modality. The advent of the helical computed tomography technique in the late 1980s allowed faster scanning and better quality of image reconstruction in arbitrary planes (Kalender *et al.* 1990). Furthermore, the introduction of multi-detector CT resulted in a major improvement in performance, as it could be used to shorten scanning time, reduce scan collimation, or increase scan length substantially (Prokop 2003). An increasing number of trauma centers are using whole-body CT for early assessment of primary trauma during the early resuscitation phase (Huber-Wagner *et al.* 2009).

Chest radiography has remained the primary technique for thoracic imaging in ICU. However, it has several well-documented limitations, including relatively low sensitivity and specificity (Chahine-Malus *et al.* 2001, Miller *et al.* 1998, Roddy *et al.* 1981, Tagliabue *et al.* 1994, Winer-Muram *et al.* 1993). Likewise, only limited information is obtained from plain abdominal radiography, and the usability of ultrasonography in ICU patients is hampered by bowel gases, wounds, catheters, tissue defects, and edemic tissues (Go *et al.* 2005). However, the use of CT examinations for ICU patients may be limited by the costs, risks, and extra workload related to the need to transfer the patient to the CT suite. Furthermore, the use of a radiocontrast agent may impair renal function and cause allergic reactions. The radiation dose also has to be considered (Kim *et al.* 2004). Systematic analyses of the overall impact of MDCT on the treatment of general ICU patients are few (Kumta *et al.* 2002, Velmahos *et al.* 1999).

GB abnormalities are frequent in ICU patients (Boland *et al.* 2000) and are considered largely a manifestation of systemic critical illness associated with multiple organ dysfunction (Laurila *et al.* 2006, Laurila *et al.* 2005). Acute acalculous cholecystitis (AAC) is a potentially fatal condition mainly affecting critically ill patients (Kalliafas *et al.* 1998, Laurila *et al.* 2004, Pelinka *et al.* 2003). Many imaging findings have also been associated with AAC, but have shown little predictive value (Boland *et al.* 2000, Puc *et al.* 2002).

The purpose of this study was to assess the significance of MDCT in diagnostics and treatment decisions concerning critically ill and multiple trauma patients. The reliability of MDCT using a dedicated trauma protocol was evaluated in blunt multiple trauma patients. The reliability and accuracy of a rapid structured evaluation of MDCT images from the scanner's console in multiple trauma patients was also studied. The impact of MDCT examinations on treatment and clinical decision-making concerning ICU patients was observed. And finally, the usefulness of CT findings in predicting necrotic AAC in ICU patients was clarified.

2 Review of the literature

2.1 Multiple blunt trauma

2.1.1 Trauma-related death

Trauma-related death has been assumed to follow a trimodal distribution with three distinct peaks correlating with immediate, early, and late death from trauma (Trunkey 1983). However, the validity of this model, which has been widely taught in the design of trauma systems, is questionable in the modern era (de Knegt *et al.* 2008, Demetriades *et al.* 2005). Still, the first peak exists (50.2% of deaths), occurring within the first hour of injury (de Knegt *et al.* 2008, Demetriades *et al.* 2005). The incidence of trauma deaths is high within the first six hours after admission, but it declines later on (Demetriades *et al.* 2005). Even when a helicopter emergency medical service enables immediate access to the accident scene and the patients are aggressively treated, no extra benefit can be seen (Iirola *et al.* 2006). The temporal distribution and location of trauma deaths are influenced by the mechanism of injury, the age of the patient, and the injured body area (Demetriades *et al.* 2004, Demetriades *et al.* 2005).

Preventable or potentially preventable deaths are rare but still occur even in high-volume trauma centers (2.5% of deaths) (Gruen *et al.* 2006, Teixeira *et al.* 2007). The most common recurrent cause of preventable death remains human error, resulting in a delay in treatment, inadequate monitoring, and missed injuries (Teixeira *et al.* 2007).

2.1.2 Radiological imaging approach for trauma patients

An increasing number of trauma centers are using whole-body CT for early assessment of primary trauma during the early resuscitation phase, even in hemodynamically unstable patients (Huber-Wagner *et al.* 2009). For a good reason, concern over the risk of overscanning patients has arisen (Wurmb *et al.* 2007). However, clinically significant injuries are not uncommon even in patients with no obvious signs of chest or abdominal injury (Salim *et al.* 2006). Recently published data suggest for the first time that the probability of survival for patients with major trauma can be significantly increased by the use of whole-body CT. The number needed to scan based on the trauma and injury severity score (TRISS) was 17 for CT covering a whole-body area (Huber-Wagner *et al.* 2009). CT is also the preferred imaging modality for a pregnant patient with major trauma, because the principle is that there can be no fetal survival without maternal survival (Chen *et al.* 2008).

A more rapid diagnostic workup may be achieved when using whole-body CT as a primary diagnostic tool compared with conventional use of radiography, combined with abdominal ultrasound and organ-focused CT (Wurmb *et al.* 2009). Furthermore, the single-pass whole-body CT protocols may result in significantly shorter scanning time than the segmental conventional protocol (Nguyen *et al.* 2009). The initial experience with the most advanced technique of a 64-row MDCT scanner indicates further time savings, especially in the reformatting and evaluation interval (Rieger *et al.* 2009).

2.2 Critically ill patients

Intra-hospital transfer of critically ill patients may pose major risks, either system based or human based (Beckmann *et al.* 2004). Patients requiring a transfer out of the ICU are a more critically ill patient group (Szem *et al.* 1995). Because the transfer of patients to an imaging room outside the ICU is potentially hazardous, the transfer process must be efficient, organized, and follow recommended practice guidelines (Beckmann *et al.* 2004, Papson *et al.* 2007, Warren *et al.* 2004). The most common unexpected events that occur are oxygen saturation probe failures, lead and line angles, hypotension, and wearing off of sedation (Papson *et al.* 2007). Intra-hospital transfers may also pose a risk for ventilator-associated pneumonia (VAP) (Bercault *et al.* 2005, Kollef *et al.* 1997). Cautious measures are recommended before and during the transfer to prevent VAP, and in the few days after the transfer, intensive searching for VAP is justified (Bercault *et al.* 2005).

2.3 Computed tomography

2.3.1 Technical development

The first CT scanners were introduced in the early 1970s (Ambrose & Hounsfield 1973). The first clinical application for this novel imaging modality was evaluation of the parenchyma of the brain. Technical evolution of CT scanners made it possible to examine a variety of abnormalities in different organ systems in a manner not previously possible. The establishment of total-body CT scanning in 1974 gradually altered the radiological approach to diagnosis of diseases (Schellinger *et al.* 1975, Sheedy *et al.* 1976). The first CT scanners in Finland were introduced in 1978 (Suoranta 2006).

The advent of continuously rotating CT scanners provided the necessary technical basis for the invention of the helical CT scanning technique (Kalender *et al.* 1990). Helical CT scanning enabled covering of extended and complete organ volumes during a single held breath (Kalender *et al.* 1990). Although three-dimensional postprocessing methods were now available due to continuous volume data, there was still a considerable mismatch between transverse (in plane) and longitudinal (axial) spatial resolutions (Klingenbeck-Regn *et al.* 1999). This drawback was overcome when subsecond multi-slice/multi-detector CT scanners were introduced in 1998 (Klingenbeck-Regn *et al.* 1999). MDCT brought a major improvement in performance, as it could be used to shorten scanning time, reduce scan collimation, or increase scan length substantially (Prokop 2003).

2.3.2 Advantages

CT has gained acceptance as the most accurate modality for imaging of the thorax and abdomen (Barkhausen *et al.* 1999, Kumta *et al.* 2002, Miller *et al.* 1998, Roddy *et al.* 1981, Tagliabue *et al.* 1994, Voggenreiter *et al.* 2000). Compared with other imaging modalities, CT is able to cover the whole body in a short moment of time, undisturbed by bowel gases, wounds, catheters, tissue defects, or edemic tissues. CT may depict faint pneumothorax and lung contusion as well as inflammatory changes in the lung more accurately than chest radiography (Ball *et al.* 2005, Elmali *et al.* 2007, Traub *et al.* 2007). Fractures of the spine and pelvis are revealed more robustly than with plain radiographs (Tables 1 and 2). Abdominal injuries and diseases are evident at least as clearly as with ultrasonography and regarding the retroperitoneal space, CT is superior to ultrasonography (Fang *et al.* 2006b).

2.3.3 Disadvantages

The patient has to be transferred to the CT suite for the scanning. Because intra-hospital transportation of severely traumatized or critically ill patients poses significant risks, the transport process should be organized and efficient.

Therefore, CT scanning should only be undertaken when the benefits outweigh the risks of the transport (Beckmann *et al.* 2004, Warren *et al.* 2004). Treatment of the patient and safe transport also necessitates the presence of ICU personnel during the scanning (Warren *et al.* 2004).

Intravascular use of an iodinated contrast agent may cause adverse reactions, which are more likely to develop in patients with asthma, a history of allergy or contrast reaction, and in those who are debilitated or medically unstable (Morcos & Thomsen 2001). The use of low-osmolar contrast media has resulted in a reduction in the incidence of severe and very severe reactions by a factor of ten in comparison with high-osmolar contrast media (Katayama *et al.* 1990). Nevertheless, the incidence of anaphylaxis or anaphylactoid reactions due to contrast media is 35 per 100,000 procedures when low-osmolar contrast media are used (The International Collaborative Study of Severe Anaphylaxis 2003).

The most commonly used definition for contrast-material-induced nephropathy (CIN) is an increase in serum creatinine of 0.5 mg/dl (44.2 μmol/l), or a 25% increase from the baseline value, assessed 48 hours after the procedure (McCullough *et al.* 2006). CIN is the third most common cause of hospital-acquired renal failure and is a substantial cause of morbidity and mortality (Tublin *et al.* 1998). Non-diabetic surgical ICU patients and ICU patients with at least one risk factor of CIN and receiving theophylline for prophylaxis present a similarly low incidence of CIN (1.4% vs. 2%) (Haveman *et al.* 2006, Huber *et al.* 2001, Huber *et al.* 2006). The highest risk of developing CIN is in patients with both diabetes and renal impairment (Halvorsen 2008). However, the relative incidence of CIN in patients who have received intravenous contrast material appears to be lower than in those who received intra-arterial contrast media (Katzberg & Barrett 2007). While the prophylactic effect of N-acetylcysteine against CIN is questionable, a volume expansion with isotonic hydration has a well-established role in reducing the risk of CIN (Gonzales *et al.* 2007, Kay *et al.* 2003, Mueller *et al.* 2002, Stacul *et al.* 2006, Tepel *et al.* 2000, Zagler *et al.* 2006).

Despite rapid volumetric scanning, CT images may still suffer from movement artifacts (Kroft *et al.* 2007). ECG gating reduces artifacts caused by heart contractile movements, but when retrospective ECG gating is applied, the radiation dose increases (Horiguchi *et al.* 2008). Metallic implants or foreign bodies may cause streak artifacts due to beam hardening, and thereby degrade image quality (Lee *et al.* 2007).

2.3.4 CT radiation dose

The CT technique is associated with a relatively high inherent radiation dose, and recent technological development with consequent changes in practice has even increased the dose burden (Dawson 2004). In order to optimize CT examinations, the radiation dose given to patients should be minimized without significantly deteriorating the diagnostic accuracy of the examinations (Kiljunen 2008). Median effective doses may range from 2 mSv for a routine head CT scan to 31 mSv for a multiphase abdomen and pelvis CT scan, but there may be even more than ten-fold variation in effective doses within and across institutions (Smith-Bindman *et al.* 2009). Although radiographs are taken much more frequently than CT scans are performed, the latter may account for up to two-thirds of the total radiation dose that critically ill patients are exposed to (Kim *et al.* 2004). Consequently, physicians should always consider the expected risks and benefits of CT scanning (Tien *et al.* 2007, Winslow *et al.* 2008). However, justification for performing CT scanning on multiple trauma and critically ill patients is definitely warranted. Exploiting novel technical innovations, e.g. in the field of detector development and noise-reducing algorithms applied to raw data, may contribute to reducing patient doses.

2.4 Computed tomography in blunt multiple traumas

2.4.1 Craniocerebral and facial injury

CT is the most relevant imaging procedure for surgical lesions (Besenski 2002, Parizel *et al.* 2005). Patients identified as having a moderate or high risk of intracranial injury (Glasgow Coma Scale score (GCS) < 13) should undergo early non-contrast CT for evidence of intracerebral hematoma, midline shift, or increased intracranial pressure (Davis & Expert Panel on Neurologic Imaging 2007). CT is relatively insensitive in detecting small and non-hemorrhagic lesions such as contusion. Diffuse axonal injuries, increased intracranial pressure, cerebral edema, or early demonstration of hypoxic-ischemic encephalopathy may go undetected on CT (Davis & Expert Panel on Neurologic Imaging 2007).

There has been much controversy about the use of CT for patients with a minor head injury (GCS score 13-15) (Haydel *et al.* 2000, Stiell *et al.* 2001). Both national and international clinical guidelines for the use of CT have been proposed and validated, but they have shown considerable overlap (Smits *et al.*

2007). All of the validated guidelines have demonstrated a trade-off between sensitivity and specificity, and none of the guidelines have proven clearly superior (Smits *et al.* 2007, Stiell *et al.* 2005).

CT is the imaging method of choice in evaluating the complex anatomic structures of the maxillo-facial region (Kubal 2008, Salonen *et al.* 2008, Salvolini 2002). CT scanning of the orbits may provide valuable information about any head trauma patient who presents one or more symptoms directly related to an orbital fracture or just isolated blepharohematoma (Exadaktylos *et al.* 2005). Helical CT is the most sensitive imaging technique for the detection of glass intraocular foreign bodies when compared with axial CT, MR imaging, and sonography (Gor *et al.* 2001). However, MR imaging may reveal wooden foreign bodies in cases where CT results have been either negative or equivocal (Kubal 2008).

2.4.2 Spinal trauma

Victims of blunt cervical spine injury needing imaging studies are initially cleared by three-view plain radiography and CT (Hashem *et al.* 2009). Plain radiography consists of anteroposterior, lateral, and odontoid views (Griffen *et al.* 2003). In some institutions oblique views are also obtained (Diaz *et al.* 2007). As shown in Tables 1 and 2, CT has proved superior to plain radiography in the detection of spinal injuries. Reflecting this growing evidence, the most widely accepted and clinically implanted guideline by the Eastern Association for the Surgery of Trauma (EAST) has been recently updated with a recommendation that the primary screening modality is axial CT from the occiput to T1 with sagittal and coronal reconstructions. Plain radiographs contribute no additional information and should not be obtained (Como *et al.* 2009).

Some controversy still exists over whether cervical MR may change management after negative CT (Menaker *et al.* 2008). While CT may fail to detect ligamentous and spinal cord injuries, virtually all unstable injuries are correctly identified (Table 1).

Blunt cerebrovascular injury (BCVI) is recognized more commonly than previously thought. The first series reporting a higher incidence of blunt carotid injury (0.67%) than appreciated was published in 1996 (Fabian *et al.* 1996). The diagnostic evaluation and management algorithm of BCVI in adult patients was recently introduced by the Western Trauma Association (Biffl *et al.* 2009). Liberal screening of BCVI with CT angiography using at least a 16-slice technique is recommended due to the high specificity and acceptable sensitivity of this modality (Biffl *et al.* 2006, Sliker *et al.* 2008). Stroke rates are shown to decrease when BCVI patients are treated appropriately (Biffl *et al.* 2002, Edwards *et al.* 2007).

The thoracic and lumbar spine is usually screened in conjunction with chest and abdominal CT scanning due to high-energy trauma (Antevil *et al.* 2006, Hauser *et al.* 2003). CT depicts thoracolumbar spine fractures more accurately than plain radiography (Table 2). However, thoracolumbar spine radiographs provide some measures (e.g. spinal canal narrowing) with acceptable precision (Bensch *et al.* 2009). When plain radiography is omitted, the time, expense, and radiation dose may be saved (Hauser *et al.* 2003, Sheridan *et al.* 2003). Since ligamentous injury of the thoracolumbar spine without bony injury is extremely rare, MR is not routinely used (Koizumi *et al.* 2002).

Table 1. Imaging for cervical spine clearance.

Author	N	Patients (guideline)	Imaging modalities	Results
(Diaz *et al.* 2003)	1006	Blunt cervical spine trauma victims	Single-slice CT and five-view plain radiography	CT Se 97.4%, Sp 100% X-ray Se 44%, Sp 100%
(Gale *et al.* 2005)	640	Blunt cervical spine trauma victims (EAST)	CT and three-view plain radiography	X-ray Se 31.6%, Sp 99.2%
(Hogan *et al.* 2005)	366	Obtunded blunt trauma victims	Four-slice or 16-slice CT and 1.5 T MRI	CT NPV 98.9% for ligamentous injury NPV 100% for unstable injury
(Como *et al.* 2007)	115	Obtunded blunt trauma victims	16-slice CT and 1.5 T MRI	MRI did not change treatment
(Mathen *et al.* 2007)	667	Patients not meeting NEXUS low-risk criteria	Four-slice CT and plain radiography	CT Se 100%, Sp 99.5% X-ray Se 45%, Sp 97.4%
(Harris *et al.* 2008)	367	Obtunded blunt trauma victims	Four-slice CT, plain radiography, and MR	CT NPV 99.7% for injury (NPV 100% for unstable injury)
(Menaker *et al.* 2008)	203	Blunt trauma victims	16-slice CT and 1.5 T MRI	MRI changed treatment in 7.9%

Author	N	Patients (guideline)	Imaging modalities	Results
(Steigelman *et al.* 2008)	120	Blunt trauma victims with altered mental status	Single-slice or four-slice CT and 1.5 or 3.0 T MRI	MRI did not change treatment
(Tomycz *et al.* 2008)	180	Obtunded trauma victims	Four-slice CT and 1.5 T MRI	CT did not miss unstable injuries
(Bailitz *et al.* 2009)	1505	Blunt cervical spine trauma victims (NEXUS)	CT and three-view plain radiography	CT Se 100% X-ray Se 36%
(Hashem *et al.* 2009)	121	Cervical spine trauma victims (EAST)	Four-slice CT and three-view plain radiography	CT Se 100% X-ray Se 61%

Table 2. Imaging for thoracolumbar spine clearance.

Author	N	Patients	Imaging modalities	Results
(Hauser *et al.* 2003)	215	High-risk trauma requiring spine screening	Single-slice CT and two-view plain radiography	CT Se 97%, Sp 99% X-ray Se 58%, Sp 93%
(Sheridan *et al.* 2003)	78	Multiple trauma patients	Single- or multi-slice CT and two-view plain radiography	CT (thoracic) Se 97% CT (lumbar) Se 95% X-ray (thoracic) Se 62% X-ray (lumbar) Se 86%
(Wintermark *et al.* 2003)	100	Severe blunt trauma	Four-slice CT and two-view plain radiography	CT Se 78.1% X-ray Se 32.0%
(Roos *et al.* 2004)	82	Patient with multiple injuries	Four-slice CT using two different collimations	CT Se 97%-98%, Sp 97%
(Antevil *et al.* 2006)	254 x-ray group + 319 CT group	Spinal trauma patients	Four-slice CT and two-view plain radiography for the thoracolumbar spine	CT Se 100% X-ray Se 70%

2.4.3 Thoracic trauma

An aortic tear is a devastating injury after blunt chest trauma. The diagnostic modality of choice has shifted from aortography to CT (Chen *et al.* 2004, Demetriades *et al.* 2008, Melton *et al.* 2004). The use of transesophageal echocardiograms (TEE) has also declined (Demetriades *et al.* 2008). Even with conventional or single-slice helical CT technology, it was possible to reliably exclude aortic injury (Cleverley *et al.* 2002, Dyer *et al.* 1999). However, the evolution of CT technology has improved diagnostic accuracy, and the prevalence of intrathoracic great vessel injury is unlikely even when a hematoma is centered around the aorta and vessels (Sammer *et al.* 2007). Therefore, a definite diagnosis of an aortic rupture is based on direct visualization of a pseudoaneurysm, an intimal flap, and aortic dissection (Ellis & Mayo 2007).

CT scanning is the "gold standard" test for lung contusion, pneumothorax, pneumomediastinum, mediastinal hematoma, as well as fractures of ribs, scapulas, and sternum (Ball *et al.* 2005, Elmali *et al.* 2007, Traub *et al.* 2007). The occult pneumothorax (OPTX) is a pneumothorax not identified on a supine plain chest radiograph (Ball *et al.* 2009, de Moya *et al.* 2007). The incidence of OPTXs may range from 30% to 76%, depending on the patient population involved, the severity of the trauma, and the skills of the interpreter (Ball *et al.* 2005, Ball *et al.* 2009, de Moya *et al.* 2007). Subcutaneous emphysema is a strong indicator of concurrent OPTX, but also pulmonary contusion, rib fractures, and female sex may predict OPTX and warrant CT scanning (Ball *et al.* 2005, Ball *et al.* 2009).

A major aerodigestive tract injury is seen in approximately 7% of patients with blunt trauma pneumomediastinum (Dissanaike *et al.* 2008). The overall sensitivity and specificity of a CT scan for a major aerodigestive tract injury is 100% and 85%, respectively (Dissanaike *et al.* 2008). CT may detect the site of a blunt tracheobronchial injury in 94% of cases (Scaglione *et al.* 2006). The Macklin effect is caused by air dissecting along bronchovascular sheaths after an alveolar rupture. This effect is identified on CT in 39% of cases with traumatic pneumomediastinum (Wintermark & Schnyder 2001). However, the Macklin effect does not preclude a tracheobronchial injury and is associated with a prolonged ICU stay (Wintermark & Schnyder 2001).

Rib fracture diagnosis is more definite on CT scans than on chest radiography, but only a CT finding of rib fractures in multiple locations is associated with increased incidence of respiratory failure (Livingston *et al.* 2008). Exploitation of the volume rendering technique may augment the diagnostic accuracy of thoracic cage fractures and even shorten the time needed for the diagnostic work up (Alkadhi *et al.* 2004).

Evidence concerning imaging of a blunt diaphragmatic rupture is still limited. Patient cohorts are small, and large prospective data and trials comparing CT scanning with MRI are lacking. Even though retrospective series have shown promising results for CT findings with sensitivity of 100%, prospective series have shown unsatisfactorily low sensitivities of 50%–67% (Allen *et al.* 2005, Nchimi *et al.* 2005, Rees *et al.* 2005). Diaphragmatic discontinuity, diaphragmatic thickening, segmental nonrecognition of the diaphragm, intrathoracic herniation of abdominal viscera, elevation of the diaphragm, and both hemothorax and hemoperitoneum have been suggested as strong predictors of a blunt diaphragmatic rupture (Nchimi *et al.* 2005).

2.4.4 Abdominal trauma

In patients who are exposed to high-energy blunt trauma and who present without clinically evident symptoms with normal radiographs and normal abdominal ultrasonography, routine use of CT reveals many clinically relevant additional injuries (Deunk *et al.* 2009). The liver and the spleen are the most common organs involved in blunt abdominal trauma (Miller *et al.* 2002, Yao *et al.* 2002). The liver and spleen organ injury scales of the American Association for the Surgery of Trauma are presented in Tables 3 and 5. Table 4 presents a CT-based liver injury severity grading system. This grading system provides criteria for selecting patients for hepatic angiography and those at increased risk of ongoing or delayed hepatic bleeding or other posttraumatic complications (Poletti *et al.* 2000). Table 6 presents an MDCT-based spleen injury grading system. This grading system is helpful in predicting which patients will need either splenic arteriography or surgery (Marmery *et al.* 2007). Identification of splenic vascular injuries on MDCT and appropriate management of these injuries are critical to achieving successful non-operative management. Therefore, an injury grade based on the AAST injury scale cannot be used as the sole criterion for guiding management (Marmery *et al.* 2007).

The reported prevalence of liver trauma among patients admitted with blunt abdominal trauma ranges from 4.6% to 6% (Malhotra *et al.* 2000, Poletti *et al.* 2000). Furthermore, concomitant liver injuries can be detected by CT in up to 25% of patients suffering from a major trauma (mean injury severity score (ISS) 35) (Matthes *et al.* 2003). Liver laceration involving the bare area of the liver (the area not covered by the peritoneum) may be associated with hemoretroperitoneum rather than hemoperitoneum (Miele *et al.* 2002, Patten *et al.* 1993).

The vast majority of hemodynamically stable patients are managed nonoperatively. Avoiding surgery decreases abdominal infections, transfusions, and the length of the hospital stay (Malhotra *et al.* 2000). Criteria based on CT findings, including hepatic injury grade, signs of arterial vascular injury, and the presence or absence of major hepatic venous involvement, may assist in the selection of patients for hepatic angiography and in the prediction of the risk of complications (Poletti *et al.* 2000). Intraperitoneal contrast extravasation and massive hemoperitoneum have been identified to independently predict the need for operative treatment in blunt liver trauma (Fang *et al.* 2006a).

Gastrointestinal injuries are rare, accounting for 1.8%–3.1% of all blunt abdominal traumas (Holmes *et al.* 2004, Watts *et al.* 2003). Small bowel injury is the most common type of gastrointestinal injury, affecting 1.1% of all blunt trauma patients, and the prevalence of perforated small bowel injury is only 0.3% (Fakhry *et al.* 2003, Watts *et al.* 2003). Stomach injury carries the highest mortality rate of 28.2%, but is also associated with the highest Injury Severity Score (ISS) (Watts *et al.* 2003).

The accuracy of CT in the diagnosis of gastrointestinal and mesenteric injuries still remains controversial. Reported sensitivities range from 76% to 95% and specificities from 48% to 96% in retrospective series (Atri *et al.* 2008, Elton *et al.* 2005, Holmes *et al.* 2004, Killeen *et al.* 2001). In prospective series sensitivities range from 64% to 95% and specificities from to 97% to 99.6% (Allen *et al.* 2004, Butela *et al.* 2001). Suggested CT findings for bowel and mesenteric injuries are bowel wall defect, extraluminal contrast material, bowel wall thickening, mesenteric vessel beading, abrupt termination of mesenteric vessels, free fluid without solid organ injury, free air, mesenteric infiltration or streaking, focal hematomas of the bowel wall or mesentery, and mesenteric vessel extravasation (Allen *et al.* 2004, Atri *et al.* 2008, Butela *et al.* 2001, Ekeh *et al.* 2008, Scaglione *et al.* 2004). Delays in the diagnosis of perforated small bowel injury beyond 24 hours are directly responsible for increased morbidity and mortality rates (Fakhry *et al.* 2000, Fakhry *et al.* 2003).

CT scanning with oral contrast material is widely used in order to aid in the identification of bowel loops, in the recognition of bowel hematoma and hemorrhage, as well as in revealing spilling of contrast material outside the bowel lumen (Butela *et al.* 2001). However, extraluminal contrast material is a rare phenomenon (Atri *et al.* 2008, Fakhry *et al.* 2003). CT imaging without oral contrast material has shown to compare favorably with CT imaging using oral contrast material (Allen *et al.* 2004, Holmes *et al.* 2004).

Table 3. AAST Liver Injury Scale (Moore *et al.* 1995).

Grade[a]	Type	Description
I	Hematoma	Subcapsular, < 10% of surface area
	Laceration	Capsular tear, < 1 cm in parenchymal depth
II	Hematoma	Subcapsular, 10%–50% of surface area; intraparenchymal, < 10 cm in diameter
	Laceration	1–3 cm in parenchymal depth, < 10 cm in length
III	Hematoma	Subcapsular, > 50% of surface area or expanding or ruptured subcapsular hematoma with active bleeding; intraparenchymal, > 10 cm or expanding or ruptured
	Laceration	> 3 cm in parenchymal depth
IV	Hematoma	Ruptured intraparenchymal hematoma with active bleeding
	Laceration	Parenchymal disruption involving 25%–75% of a hepatic lobe or one to three Couinaud's segments within a single lobe
V	Laceration	Parenchymal disruption involving > 75% of a hepatic lobe or more than three Couinaud's segments
	Vascular	Juxtahepatic venous injuries (i.e., retrohepatic vena cava or central major hepatic veins)
VI	Vascular	Hepatic avulsion

[a]Advance one grade for multiple injuries up to grade III

Table 4. CT-based injury severity of blunt liver trauma (Mirvis *et al.* 1989).

Grade	Description
I	Capsular avulsion, superficial laceration(s) < 1 cm deep, subcapsular hematoma < 1 cm maximal thickness, periportal blood tracking only
II	Laceration(s) 1-3 cm deep, central/ subcapsular hematoma(s) 1-3 cm in diameter
III	Laceration(s) > 3 cm deep, central/ subcapsular hematoma(s) > 3 cm in diameter
IV	Massive central/ subcapsular hematoma > 10 cm, lobar tissue destruction (maceration) or devascularization
V	Bilobar tissue destruction (maceration) or devascularization

Table 5. AAST Spleen Injury Scale (Moore *et al.* 1995).

Grade[a]	Type	Description
I	Hematoma	Subcapsular, < 10% of surface area
	Laceration	Capsular tear, < 1 cm in parenchymal depth
II	Hematoma	Subcapsular, 10%-50% of surface area intraparenchymal, < 5 cm in diameter
	Laceration	Capsular tear, 1-3 cm in parenchymal depth that does not involve a trabecular vessel
III	Hematoma	Subcapsular, > 50% of surface area or expanding; ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma > 5 cm or expanding
	Laceration	> 3 cm in parenchymal depth or involving trabecular vessels
IV	Laceration	Laceration involving segmental or hilar vessels producing major devascularization (> 25% of spleen)
V	Laceration	Completely shattered spleen
	Vascular	Hilar vascular injury with devascularized spleen

[a]Advance one grade for multiple injuries up to grade III

Table 6. MDCT-based spleen injury grade (Marmery *et al.* 2007).

Grade	Description
I	Subcapsular hematoma < 1 cm thick, laceration < 1 cm in parenchymal depth, parenchymal hematoma < 1 cm in diameter
II	Subcapsular hematoma 1–3 cm thick, laceration 1–3 cm in parenchymal depth, parenchymal hematoma 1–3 cm in diameter
III	Splenic capsular disruption, subcapsular hematoma > 3 cm thick, laceration > 3 cm in parenchymal depth, parenchymal hematoma > 3 cm in diameter
IV A	Active intraparenchymal and subcapsular splenic bleeding, splenic vascular injury (pseudoaneurysm or arteriovenous fistula), shattered spleen
IV B	Active intraperitoneal bleeding

2.4.5 Retroperitoneal trauma

Retroperitoneal injuries occur in a minority of abdominal trauma patients (Porter & Singh 1998). The sensitivity of a 16- and 64-slice CT scanner for blunt pancreatoduodenal injury, pancreatic injury, and duodenal injury is 82.8%, 47.2%–79%, and 50%, respectively (Phelan *et al.* 2009, Velmahos *et al.* 2009). The sensitivity and specificity of CT for pancreatic ductal injury representing a high-grade injury is 52.4%–91% and 90.3%–94.8%, respectively (Phelan *et al.* 2009, Teh *et al.* 2007). Non-operative management of a low-grade pancreatoduodenal injury (i.e. contusion or laceration without duct injury (Table

7)) is safe. However, due to its low sensitivity, CT cannot be considered a highly reliable decision-making tool (Phelan *et al.* 2009, Velmahos *et al.* 2009). Fortunately, diagnostic delays do not commonly cause disastrous outcomes (Velmahos *et al.* 2009). The pancreas organ injury scale of the AAST is presented in Table 7.

The prevalence of adrenal hemorrhage in trauma patients is approximately 2%. Adrenal injury presents as a part of a multiple trauma, with liver trauma as the most common lesion, and is associated with a higher mortality rate than in control patients (Burks *et al.* 1992, Rana *et al.* 2004). The right adrenal gland is more frequently injured (Burks *et al.* 1992, Pinto *et al.* 2006, Rana *et al.* 2004).

CT is routinely used to diagnose and characterize traumatic renal injuries. The AAST grading system for renal injuries has been validated and may be used to prognosticate both morbidity and mortality in renal injuries (Table 8) (Kuan *et al.* 2006). CT findings of active hemorrhage are strongly associated with the need for immediate surgical or angiographic intervention (Willmann *et al.* 2002). Conservative management of major blunt renal trauma is appropriate in hemodynamically stable patients (Bozeman *et al.* 2004). CT cystography is an expedient method for evaluating a bladder rupture, with 95%–100% sensitivity and 100% specificity (Chan *et al.* 2006, Deck *et al.* 2001). Gross hematuria with a pelvic rupture is an absolute indication for immediate cystography (Morey *et al.* 2001). Accurate identification of the type of bladder injury is of paramount importance. Surgical repair is required for an intraperitoneal rupture and combined intraperitoneal and extraperitoneal ruptures, whereas catheter drainage is appropriate for an extraperitoneal rupture (Chan *et al.* 2006).

Table 7. AAST Pancreas Injury Scale (Moore *et al.* 1990).

Grade[a]	Type	Description
I	Hematoma	Minor contusion without duct injury
	Laceration	Superficial laceration without duct injury
II	Hematoma	Major contusion without duct injury or tissue loss
	Laceration	Major laceration without duct injury or tissue loss
III	Laceration	Distal transection or parenchymal injury with duct injury
IV	Laceration	Proximal[b] transection or parenchymal injury involving ampulla
V	Laceration	Massive disruption of pancreatic head

[a]Advance one grade for bilateral injuries up to grade III

[b]Proximal pancreas is to the patients' right of the superior mesenteric vein

Table 8. AAST Kidney Injury Scale (Moore *et al.* 1989).

Grade[a]	Type	Description
I	Contusion	Microscopic or gross hematuria, urological studies normal
	Hematoma	Subcapsular, nonexpanding without parenchymal laceration
II	Hematoma	Nonexpanding perirenal hematoma confirmed to renal retroperitoneum
	Laceration	Parenchymal depth of renal cortex < 1.0 cm without urinary extravasation
III	Laceration	Parenchymal depth of renal cortex > 1.0 cm without collecting system rupture or urinary extravasation
IV	Laceration	Parenchymal laceration extending through the renal cortex, medulla, and collecting system
	Vascular	Main renal artery or vein injury with contained hemorrhage
V	Laceration	Completely shattered kidney
	Vascular	Avulsion of renal hilum that devascularizes the kidney

[a]Advance one grade for bilateral injuries up to grade III

2.5 Computed tomography in critically ill patients

2.5.1 Thoracic imaging

Bedside chest radiography is frequently an inadequate imaging tool for resolving complicated thoracic problems. The value of thoracic CT varies, mainly depending on the patient population and consequent changes in clinical management which have been regarded significant. In a general ICU setting, thoracic CT has revealed new clinically important findings not evident in chest radiography in 30% of examinations. From 22% to 26% of the findings have resulted in changes in clinical management (Miller *et al.* 1998, Roddy *et al.* 1981, White *et al.* 1999). With regard to ICU patients with multiple traumas, thoracic

CT has given significant additional information in 57%–70% of cases (Mirvis *et al.* 1987, Voggenreiter *et al.* 2000). ICU patients suffering from acute extremely severe respiratory failure and treated with extracorporeal membrane oxygenation present an extreme diagnostic challenge. This patient group has also benefited from thoracic CT, which has revealed complications in 19% of cases, directly impacting treatment (Lidegran *et al.* 2005). CT has proven superior to chest radiography in detecting pneumothorax, hemothorax, pericardial tamponade, mediastinal hematoma, pleural effusion, pulmonary abscess, pneumonia, postoperative fluid collection, and malignancy (Lidegran *et al.* 2005, Miller *et al.* 1998, Voggenreiter *et al.* 2000).

The diagnostic power of CT pulmonary angiography (CTPA) in detecting acute pulmonary embolism is well established (Hayashino *et al.* 2005). However, only a few studies deal with ICU patients. The incidence of deep venous thrombosis in the ICU population is estimated to be 9.6%–33% (Cook *et al.* 2005, Hirsch *et al.* 1995, Major *et al.* 2003). Pulmonary emboli have been diagnosed in only 6% of CTPA scans in ICU patients admitted for more than 24 hours (Licht *et al.* 2008). Up to 25% of CTPA scans may remain non-diagnostic due to poor contrast opacification, respiratory motion or other artifacts, and concomitant disease (Kelly *et al.* 2006). Risk factors associated with pulmonary emboli are head injury, spine injury with neurological impairment, and lower limb injury (Licht *et al.* 2008). Indirect CT venography may serve as an alternative to sonography in the evaluation of acute deep venous thrombosis (Kelly *et al.* 2006, Taffoni *et al.* 2005).

Thoracic CT has modified the view and understanding of the pathophysiology of acute respiratory distress syndrome (ARDS) (Gattinoni *et al.* 1986, Maunder *et al.* 1986). A reticular pattern, with a striking anterior distribution, is a frequent finding of follow-up CT after ARDS (Desai *et al.* 1999). Pulmonary thin-section CT findings suggestive of extensive abnormalities indicative of the fibroproliferative phase of diffuse alveolar damage are proposed to independently predict poor prognosis in patients with clinically early ARDS (Ichikado *et al.* 2006). Microbiologically provable ventilator-associated pneumonia (VAP) occurs more frequently in patients with ARDS than in other ventilator patients (Chastre *et al.* 1998). In patients with ARDS, thoracic CT has fair diagnostic accuracy for VAP. CT may help identify patients who do not have pneumonia, although no single radiological sign has proven to reliably predict the presence of pneumonia (Winer-Muram *et al.* 1998). Up to 27% of patients with negative or non-diagnostic CXR may present CT findings consistent with pneumonia (Hayden & Wrenn 2009). In an appropriate clinical setting, CT may be either suggestive of an etiology of underlying pulmonary disease (e.g Wegner granulomatosis, cryptogenic organizing pneumonia, or viral pneumonias) or it may help to narrow a list of alternative differential diagnoses (e.g. excluding Pneumocystis jiroveci pneumonia) (Franquet *et al.* 2003, Hidalgo *et al.* 2003, Kim *et al.* 2003, Lee *et al.* 2003, Wong *et al.* 2004). Patients with acute interstitial pneumonia are more likely to develop honeycombing and have a greater tendency to have a predominantly lower lung zone and bilateral symmetric distribution of parenchymal abnormalities than patients with ARDS. However, CT findings of acute interstitial pneumonia significantly overlap with those of ARDS (Tomiyama *et al.* 2001).

2.5.2 Abdominal imaging

CT is the preferred imaging modality in the evaluation of post-operative abdominal sepsis and sepsis following major trauma (Go *et al.* 2005, Velmahos *et al.* 1999). The reported sensitivity and specificity of CT is 95%–97.5% and 61.5%–91%, respectively (Meeson *et al.* 2009, Velmahos *et al.* 1999). The predictive value of CT is even better for ICU patients than for patients on wards (Go *et al.* 2005). In a critically ill ICU patient who is suffering from an infection with multisystem organ failure cessation of antimicrobial therapy cannot be based on a resolution of clinical signs only. A CT examination is likely the most appropriate means for determining if cessation of therapy can be done (Solomkin & Mazuski 2009).

GB abnormalities are frequent in ICU patients (Boland *et al.* 2000) and are considered largely a manifestation of systemic critical illness (Laurila *et al.* 2005) associated with multiple organ dysfunction (Laurila *et al.* 2006). Acute acalculous cholecystitis (AAC) is a potentially fatal condition mainly affecting critically ill septic (Laurila *et al.* 2004), trauma (Pelinka *et al.* 2003), and postoperative patients (Kalliafas *et al.* 1998). Many imaging findings, including GB wall thickening, GB distension, intramural GB lucencies, pericholecystic fluid, GB sludge, and sonographic Murphy's sign, have also been associated with AAC, but have shown little value in predicting AAC (Boland *et al.* 2000, Puc *et al.* 2002). A GB wall thickness of more than 3–4 mm has been considered a major criterion of AAC (Bennett *et al.* 2002, Boland *et al.* 2000, Mariat *et al.* 2000, Mirvis *et al.* 1986, Pelinka *et al.* 2003, Puc *et al.* 2002). Subserosal edema is also widely considered a major criterion for imaging diagnosis of AAC (Fidler *et al.* 1996, Kalliafas *et al.* 1998, Mirvis *et al.* 1986). Gas in the GB wall or lumen, an irregular or absent gallbladder wall, intraluminal membranes, pericholecystic abscess, and a lack of GB wall enhancement are postulated as specific CT findings of acute cholecystitis complicated by gangrene (Bennett *et al.* 2002).

2.6 Other imaging modalities

2.6.1 Plain films

Chest radiographs (CXRs) are often routinely taken of patients receiving invasive mechanical ventilation to verify the right position of the endotracheal tube or central venous devices, and to diagnose complications such as ventilator-associated pneumonia (VAP), pulmonary edema, and pneumothorax (Clec'h *et al.* 2008). Reports supporting daily use of CXRs are based on the argument that a considerable amount of new major findings are discovered only by chest radiography (Brainsky *et al.* 1997, Hall *et al.* 1991). The major limitation of these studies is the lack of a control patient group. Recently published data strongly support abandonment of daily routine CXRs (Table 9). After a straightforward central venous catheter placement, routine CXR is not required (Bailey *et al.* 2000). The strategy of restrictive use of CXRs yields better diagnostic and therapeutic efficacies without any negative effect on the length of stay in the ICU, the outcome, or the readmission rate to the ICU (Clec'h *et al.* 2008, Hendrikse *et al.* 2007, Krivopal *et al.* 2003, Kroner *et al.* 2008, Mets *et al.* 2007). No effect on either chest CT or ultasonography practice has been found either (Kroner *et al.* 2008). Furthermore, the reduction in the number of CXRs per patient per day results in a cost reduction (Hendrikse *et al.* 2007).

Table 9. Use of daily chest radiographs in the ICU.

Author	Number of patients	Efficacy of daily chest radiographs	Effect of restricted use on chest radiographs	Effect of restricted use on outcome or other imaging
(Brainsky et al. 1997)	80	Diagnostic efficacy 33% and therapeutic efficacy 8%		
(Chahine-Malus et al. 2001)	198	Therapeutic efficacy 17% - 26%	Therapeutic efficacy 40%	
(Krivopal et al. 2003)	94	Diagnostic efficacy 33.4% and therapeutic efficacy 13.3%	Diagnostic efficacy 53.1% and therapeutic efficacy 26.5%	No effect on patient outcome
(Graat et al. 2006)	754	Diagnostic efficacy 5.8% and therapeutic efficacy 2.2%		
(Mets et al. 2007)	338		Decrease in chest radiographs per patient day from 1.8 ± 0.6 to 1.1 ± 0.6	No effect on chest radiography practice in the post-ICU ward
(Hendrikse et al. 2007)	486	Diagnostic efficacy 4.4% and therapeutic efficacy 1.9%	Decrease in chest radiographs per patient day 35%	No effect on patient outcome
(Kroner et al. 2008)	1490		Decrease in chest radiographs per patient day from 1.1 ± 0.3 to 0.6 ± 0.4	No effect on chest CT and ultrasound practice
(Clec'h et al. 2008)	165	Diagnostic efficacy 7.2% and therapeutic efficacy 5.5%	Diagnostic efficacy 66% and therapeutic efficacy 56.4%	No effect on patient outcome

2.6.2 Sonography

Utrasonography is employed in a prehospital setting by physicians, military medics, and emergency medical services personnel. Modern portable utrasonography machines are feasible in the field for diagnosing conditions such as pleural, peritoneal, and pericardial effusion and deep venous thrombosis (Busch 2006, Lapostolle *et al.* 2006, Walcher *et al.* 2006).

Utrasonography is a versatile bedside imaging modality in the ICU. Major advantages are the lack of ionizing radiation and the ability to guide interventional procedures. However, certain anatomical areas are difficult to visualize, and their examination can be hampered by wounds, surgical dressings, drains, and the presence of an ileus (Go *et al.* 2005). ICU physicians use utrasonography to assess pleural effusion, lung consolidation, and even lung re-aeration and the presence of pneumothorax (Bouhemad *et al.* 2010, Lichtenstein *et al.* 2004, Zhang *et al.* 2006). Cardiac assessment is also routinely performed with ultrasonography (Jensen *et al.* 2004).

The main application for sonography in trauma patients is detection of free fluid. Unfortunately, even in the skilled hands of trauma team radiologists, this examination, known by the acronym FAST (focused assessment with sonography for trauma), cannot reliably exclude intra-abdominal bleeding in hemodynamically unstable patients (Gaarder *et al.* 2009). Contrast-enhanced ultrasonography (CEUS) appears to be both more sensitive and more specific than sonography in the detection of solid organ injury (Catalano *et al.* 2009, McGahan *et al.* 2006, Valentino *et al.* 2006). Further research is needed to find out if CEUS has the potential to reduce the use of CT as a screening method.

2.6.3 Magnetic resonance imaging

MRI is the modality of choice for imaging the central nervous system and spinal soft tissues. Ligamentous injury of the thoracolumbar spine without bony injury occurs extremely rarely (Hirsh *et al.* 1993, Koizumi *et al.* 2002, Van Buul & Oner 2009). The indications for MRI of the thoracolumbar spine after blunt trauma are fractures with neurologic deficits, CT scan findings, and pain on clinical examination without radiographic abnormalities concerning ligamentous injury (MacMillan & Stauffer 1990). A NPV of 100% for correctly depicting true negative findings warrants the use of MRI for clearing the cervical spine in a clinically suspicious blunt trauma patient (Albrecht *et al.* 2001, D'Alise *et al.* 1999, Koivikko & Koskinen 2008, Menaker *et al.* 2008). MRI readily depicts the presence of a diffuse axonal injury, which is the most common primary lesion in patients with traumatic brain injury and which may be the most common cause of a poor outcome (Parizel *et al.* 1998, Parizel *et al.* 2005). Furthermore, MRI may be used as a complementary imaging modality with CT, e.g. in trauma patients with iodinated contrast agent allergy and impaired renal function (without gadolinium contrast agent) (Leppaniemi *et al.* 1995).

2.7 Radiologists as part of a multidisciplinary team

The chest radiograph is considered one of the most complex imaging modalities to interpret. Emergency department physicians frequently miss specific radiographic abnormalities and there is considerable discrepancy between their interpretations and those of trained radiologists (Gatt *et al.* 2003). Cooperation between emergency physicians and radiologists reduces errors in interpretation of radiographs and potential adverse events due to misdiagnoses (Espinosa & Nolan 2000). The majority of errors made by radiologists are false negative interpretations, and they occur during CT image interpretation. A significant proportion of errors result from departmental miscommunication (McCreadie & Oliver 2009). When a radiologist is doing a FAST on a trauma patient, he becomes well informed of the details of the accident and further treatment plans for the patient. Clinical-radiological consultations are time-consuming (21.65 minutes per day per radiologist or 13% of a 24-hour period for the attending radiologist), but they have a beneficial diagnostic and therapeutic impact on patient care (Dalla Palma *et al.* 2000, Viscomi *et al.* 2004).

2.8 Statistical measures

Sensitivity (Se) measures the proportion of actual positives that are correctly identified as such. Specificity (Sp) measures the proportion of negatives that are correctly identified. Accuracy is the proportion of true results (both true positives and true negatives).

Table 10. Test T.

	Disease D	
	D+*	D-**
T+	True positive	False positive
T-	False negative	True negative

	D+	D-
T+***	a	b
T-****	c	d

Sensitivity	Se = Pr (T+ | D+) = a/ (a + c)
Specificity	Sp = Pr (T-| D-) = d/ (b + d)
Accuracy	(a + d)/ (a + b + c + d)

*D+ = Patient has the disease D

**D- = Patient does not have the disease D

***T+ = Result of the test T is positive

****T- =Result of the test T is negative

3 Purpose of the study

The purpose of this study was to assess the significance of Multi-Detector Computed Tomography in diagnostics and treatment decisions concerning multiple trauma and critically ill patients. Particular interest was focused on the following questions:

1. Is MDCT using a dedicated trauma protocol reliable and able to provide sufficient diagnostic information about blunt multiple trauma patients to enable planning of treatment for all body compartments?
2. How reliable and accurate is a rapid, structured evaluation of MDCT images from the scanner's console in multiple trauma patients?
3. How often do MDCT examinations lead to a change in treatment and have some other impact on clinical decision-making concerning ICU patients?
4. Does MDCT provide useful information about AAC in ICU patients?

4 Patients and methods

4.1 Study population

This study was conducted at Oulu University Hospital, which is a tertiary-level teaching hospital with over 100,000 treated patients per year. The mixed medical-surgical ICU was a 12-bed unit with approximately 940 admissions per year. The general demographic data of the patients in the original articles are presented in Table 11.

In retrospective study I, all the patients from October 2001 through November 2002 who were suspected of being a victim of high-energy trauma and who were scanned with MDCT using the standardized multiple trauma protocol were eligible for the study. Hemodynamically unstable patients were not appropriate for MDCT scanning. The criteria of a high-energy trauma were based on the indications listed by Grande & Stene (1991), (Appendix, Table 19). The same inclusion criteria were applied prospectively in study II to high-energy trauma patients from April 2002 to December 2002. The availability of raw data that enabled evaluation of MDCT images from the scanner's screen was also an inclusion criterion.

In study III, from February 2004 through November 2004, all the consecutive patients who stayed in the ICU for more than 48 h and underwent MDCT were entered into the study prospectively. Neurosurgical patients and head scans were excluded. MDCT examinations were conducted when clinical data, radiography, and ultrasonography were inconclusive or were not considered reliable enough for decision-making. The indications for MDCT included a need to identify a possible focus of infection, a suspected malignancy, or deteriorating organ function (e.g. respiratory or gastrointestinal) in cases where both clinical information and other radiological imaging modalities (plain radiography or ultrasonography) were inconclusive.

In retrospective study IV, patients admitted to the ICU from January 2001 through December 2006 who had undergone abdominal computed tomography scanning were entered into the study. The AAC group consisted of patients who had undergone CT scanning within 72 hours before open cholecystectomy due to suspected AAC. Patients in a similar age group admitted to the ICU during the same period of time and having undergone abdominal computed tomography served as controls. The control patients had neither undergone cholecystectomy before their admission nor during their ICU stay. Indications for open cholecystectomy due to AAC in our ICU were based on the patients' clinical status, radiological examinations (ultrasonography, CT), and laboratory tests, and were made by a multi-specialist ICU team (intensivist, GE surgeon, and infectious disease specialist).

Table 11. General demographic data of the patients and study design in the original articles.

Study	Study design	N (male/female)	Age, years mean (range)[SD]	CT examinations	Scanned area
I	retrospective	133 (101/32)	35 (6–80) male 41 (5–92) female	133	Head, facial bones, cervical spine, thorax, abdomen, and pelvis
II	prospective	40 (32/8)	38 (7–92)	40	Thorax, abdomen, and pelvis
III	prospective	64 (46/18)	57.3 [14.5]	82	Paranasal sinuses, neck, thorax, abdomen, pelvis, and upper thigh
IV	retrospective	127 (91/36)	63 (17-83)	127	Abdomen

4.2 Main outcome variables and parameters

For studies I and II, medical records were reviewed for age, gender, and mechanism of injury. For study I, MDCT findings related to trauma were retrieved from radiological reports. These findings were compared with radiological imaging follow-up studies, operative findings, and the clinical follow-up. For evaluation of the radiological imaging data, the body was divided into five compartments: 1) head, 2) thorax including ribs, clavicles, and scapulas, 3) abdomen, 4) urinary system and retroperitoneum, and 5) spine and pelvic bones.

In study II, MDCT findings related to trauma were evaluated in a rapid screening test lasting a maximum of five minutes. The screening findings were compared with the final radiological diagnosis of the MDCT data made by experienced trauma radiologists, the operative findings, and the clinical follow-up. In the evaluation of the data, the body was divided into four compartments: 1) the thorax, including the ribs, 2) the abdomen, 3) the urinary system combined with the retroperitoneum, 4) and the spine combined with the pelvic bones, scapula, clavicles, and hips.

In study III, for each examination a prospective assessment of the impact of the MDCT findings on the patient's treatment was made by a multidisciplinary evaluation group, who reviewed the decisions made by the attending physician in each case. The treatment interventions following the MDCT examination were classified as surgical intervention, percutaneous intervention, change in antimicrobial medication, withdrawal of active treatment, or other change in treatment. The need for additional examinations was also noted. Possible adverse events during transportation to and from the MDCT suite were verified. Radiocontrast-induced nephropathy was defined as a 25% increase in creatinine from the baseline level at 48 h or a need for renal replacement therapy after exposure to the radiocontrast medium.

In study IV the following data were extracted from the hospital records and the ICU's data management system (Centricity Critical Care Clinisoft®, GE Healthcare, Helsinki, Finland): age, sex, admission diagnosis, outcome, Acute Physiology and Chronic Health Evaluation (APACHE) II score, Simplified Acute Physiology Score (SAPS) II and Sequential Organ Failure Assessment (SOFA) score on the date when the CT scanning was performed, and the length of stay in the ICU. C-reactive protein, white blood cell count, the results of liver function tests, the use of opioids, corticosteroids, vasoactive, and sedative drugs were recorded as well. Failure of the respiratory, cardiovascular, renal, coagulation, hepatic, or central nervous organ system was defined as a SOFA score ≥ 3, according to Vincent *et al.* (Vincent *et al.* 1996, Vincent *et al.* 1998). The CT images were reviewed for the following findings: bile density, thickness and enhancement of the GB wall, subserosal edema, greatest perpendicular diameters of the GB, width of extra hepatic bile ducts, gas within the gall bladder, ascites, peritoneal fat edema, and diffuse tissue edema. The operative findings for the GB were retrieved from medical records.

4.3 Imaging methods

4.3.1 Multiple blunt trauma patients (studies I and II)

The MDCT scans were obtained with a 4-row MDCT scanner (Toshiba Aquilion; Toshiba Medical Systems; Tokyo, Japan). The standardized imaging protocol consisted of axial scanning of the head and helical scanning of the facial bones, cervical spine, thorax, abdomen, and pelvis. The scanning parameters for the head were 2 mm collimation, 4 mm image thickness at the level of the skull base, and 8 mm image thickness above the skull base, 120 kV, 300 mAs, and 1.5 s gantry rotation time. The cervical spine was examined from the occipital condyles to T1, using 1 mm collimation, 1 mm image thickness, 1 mm overlapping, pitch of 5.5, 120 kV, 150 mAs, and 0.5 s gantry rotation time. If there was a suspicion of facial trauma, cervical spine scanning was extended above the orbits.

First the patient's upper extremities were kept adjacent to the body, but before the scanning of the thorax and abdomen they were moved adjacent to the head. The scanning of the thorax, abdomen, and pelvis was performed with 2 mm collimation, 3 mm image thickness, 2 mm overlapping, pitch of 5.5, 120 kV, 150 mAs, and 0.5 s gantry rotation time. One hundred and forty ml of contrast material was administered intravenously at 3 ml/s (Ultravist 300 mg I/ml; Schering, Berlin, Germany). In all the patients, the delay from initiation of the bolus injection to the start of scanning was 50 s. None of the patients received oral contrast material. In the case of younger and smaller patients, the tube current and the volume of intravenously administered contrast material were reduced according to the patient's body weight.

Images for evaluation on the scanner's console were reconstructed using the real-time image reconstruction (RTIR) technique. With the RTIR technique, the image is initially reconstructed from the complete 360° data set on the first rotation of the scanning. After this, image data are updated at every 60° of rotation. This yields 12 image frames per second using a 256 x 256 matrix, and 8 image frames per second using a 512 x 512 matrix.

4.3.2 Intensive care unit patients (studies III and IV)

In study III the MDCT scans were obtained with a four-row MDCT scanner (Toshiba Aquilion; Toshiba Medical Systems; Tokyo, Japan). The neck, thorax, and abdomen were scanned with 2 mm collimation, 1.5–2 mm overlapping, 5.5

pitch, 120 kV, and 0.5 s gantry rotation time. Tube current and the dose of intravenously administered non-ionic contrast material (Visipaque® 270 mgI/ml, or Omnipaque® 300 mgI/ml; GE Healthcare; London, UK, or Ultravist® 300 mgI/ml; Berlin, Germany; 100–140 ml) were adjusted according to the patient's body weight and the scanned anatomical area. The delay from the start of the bolus injection to the initiation of scanning was 40–50 s for the neck, 40–60 s for the thorax, and 70–80 s for the abdomen. In patients with impaired renal function, in addition to adequate fluid expansion with intravenous saline, N-acetylcystein was administered before and after the scanning, and iodixanol (Visipaque®) was used as the contrast agent.

In study IV, CT scans were obtained using the helical technique with either a one-row (HiSpeed, General Electric Medical Systems, Milwaukee, WI), a four-row (Toshiba Aquilion, Toshiba Medical Systems, Tokyo, Japan), or a 16-row scanner (LightSpeed, General Electric Medical Systems, Milwaukee, WI). The patients received non-ionic contrast material unless it was contraindicated (e.g. due to previous severe allergic reaction or severely impaired renal function). Slice thickness varied from 1.2 mm to 5 mm.

4.4 Image assessment

In study I the image data were evaluated on a PACS workstation equipped with a multiplanar reformatting tool using three different window settings: lung (WW 2000, WL 2700), soft tissue (WW 400, WL 40), and bone (WW 2000, WL 350). If the MDCT examination was conducted outside office hours, an experienced senior radiologist verified the examination and the final report and produced a complementary report, if needed.

In study II the images were scrolled on the scanner's console, and two board-certified trauma radiologists and four resident radiologists with 4 to 6 years of experience did a prospective structured evaluation of the traumatic lesions. The same window settings were used as in study I. A structured, multiple-choice injury report covering all organ systems was completed and given to the attending physician before the trauma team left the MDCT room. In order to minimize diagnostic delay in the treatment of potentially life-threatening injuries, screening time was limited to 5 min. The final radiological diagnosis of the MDCT data was made on a PACS workstation (EasyVision 4.4 or ViewForum 4.1; Philips; Eindhoven, The Netherlands) by the attending radiologist. If the attending radiologist was a resident, then a senior radiologist verified the diagnosis during office hours.

In study III the MDCT report was made by an experienced radiologist based on an evaluation of the images on a PACS workstation. For study IV the computed tomography images were recalled from the digital image archive and reviewed separately by two experienced abdominal radiologists (L.A. and A.J.) using a PACS workstation (Advantage Workstation 4.3, General Electric Medical Systems, Waukesha, WI). The reviewers were blinded from the surgical operative findings and clinical parameters, but were aware that all the patients were treated in the ICU, and that among them were patients with AAC. The reviewers analyzed the CT images, identifying or measuring the following findings: bile density, thickness and enhancement of the GB wall, subserosal edema, greatest perpendicular diameters of the GB, width of extra hepatic bile ducts, gas within the gall bladder, ascites, peritoneal fat edema, and diffuse tissue edema.

4.5 Statistical analysis

The data in the present study were analyzed using cross-tabulation. The sensitivity and specificity of the MDCT examinations were calculated in studies I, II, and IV, and accuracy in study I.

In study III the data were presented as means and standard deviations (SD) or as medians and 25th and 75^{th} percentiles, as appropriate, and comparisons between the groups were done by χ^2 test.

In study IV, summary measurements were presented as means with standard deviation (SD) or as medians with 25th and 75th percentiles. Analysis of variance (ANOVA) or the Kruskal-Wallis test (the latter with non-normal data) was used when comparing continuous variables between the control group and different operative findings (normal, edemic AAC, and necrotic or perforated AAC). Categorical data were analyzed using the Chi-square test or Fisher’s exact test. Spearman’s correlation coefficient (ρ) was calculated. Two-tailed P-values were presented. The analyses were conducted using SPSS (version 16.0, SPSS inc., Chicago, Ill.).

5 Results

5.1 Main clinical results (I–IV)

Ninety-nine out of 133 patients (74%) had at least one MDCT finding consistent with trauma when the criteria of high-energy trauma were fulfilled. Nineteen patients (14%) had additional findings unrelated to trauma, and 34 (26%) had normal findings. The overall sensitivity of MDCT was 94%, specificity 100%, and accuracy 97% (I). Evaluation from the scanner's console enabled rapid diagnosis of all potential life-threatening injuries, the sensitivity for all injuries being 60% and specificity 98% (II).

Fifty out of 82 MDCT examinations (61%) resulted in a change in treatment in patients with a general ICU stay longer than 48 h. Twenty examinations (24%) were regarded as otherwise necessary for clinical decision-making, although no change in treatment was indicated. Twelve examinations (15%) failed to provide any additional information relevant to the patient's treatment (III).

Abnormal CT findings in the gallbladder were present in 96% of the ICU patients. Higher bile density in the gallbladder body and subserosal edema were associated with an edematous gallbladder (Sp 93.6%, Se 23.1%). The most specific findings predicting necrotic AAC were gas in the gallbladder wall or lumen, lack of gallbladder wall enhancement, and edema around the gallbladder (Sp 99.2%, 94.9%, and 92.4%, and Se 11.1%, 37.5%, and 22.2%, respectively) (IV).

5.2 Accuracy of computed tomography in multiple trauma diagnostics (I)

The MDCT findings consistent with trauma were divided into five separate compartments and presented in Table 12. Two patients (2%) underwent craniotomy immediately after the MDCT examination. There were no thoracic injuries requiring thoracotomy. Nine spleen lacerations included two grade I, four grade II, and three grade III injuries. Ten renal lacerations included two grade II, three grade III, one grade IV, and one grade V injury. Three renal injuries were not graded. Six liver lacerations included two grade II, three grade III, and one grade IV injury. Seven patients (5%) underwent laparotomy immediately after the MDCT examination. MDCT revealed several injuries in these patients, and all of them had free fluid in the abdominal cavity. In a later phase (1–4 days), three patients (2%) underwent laparotomy due to symptoms and clinical findings of peritonitis: all of these patients had an intestinal rupture that had gone undetected in the primary MDCT examination.

Forty-two patients (32%) had findings in a single compartment, and altogether 57 of the 133 patients (43%) had injuries in two or more compartments. Thirty-three patients (25%) had injuries in two compartments, 17 patients (13%) in three compartments, five patients (4%) in four compartments, and two patients (2%) in all five compartments.

Follow-up examinations, surgery, and clinical outcome revealed 19 false negative findings and two false positive findings (Table 13). Follow-up MDCT examinations, especially of the head, revealed several findings that had developed or progressed after the first and second surveys. Progressive findings of the head were seen in 11 patients (8%) with three new subdural hematomas.

Table 12. MDCT findings in patients exposed to high-energy trauma.

	Head 37/133 (28%)	Thorax 58/133 (44%)	Abdomen 29/133 (22%)	Retroperitoneal space 18/133 (14%)	Spine and pelvic bones 43/133 (32%)
Contusion	18/37 (14%)				
Intracranial hematoma	14/37 (11%)				
Skull fracture	14/37 (11%)				
Facial bone fracture	10/37 (8%)				
Hemothorax		23/58 (17%)			
Rib fracture		23/58 (17%)			
Pneumothorax		11/58 (8%)			
Pulmonary contusion		11/58 (8%)			
Clavicular fracture		8/58 (6%)			
Scapular fracture		3/58 (2%)			
Pneumo-mediastinum		1/58 (1%)			
Hemoperitoneum			12/29 (9%)		
Hematoma adjacent to the liver			10/29 (8%)		
Hematoma adjacent to the spleen			10/29 (8%)		
Spleen laceration			9/29 (7%)		
Liver laceration			6/29 (5%)		
Intestinal contusion			1/29 (1%)		
Intestinal perforation			1/29 (1%)		
Kidney laceration				10/18 (8%)	
Hematoma adjacent to the kidney				8/18 (6%)	
Retroperitoneal hematoma				7/18 (5%)	
Urinary bladder rupture				2/18 (2%)	
Kidney infarction				1/18 (1%)	
Scrotal contusion				1/18 (1%)	
Spine fracture					29/43 (22%)
Pelvic fractures					16/43 (12%)

Table 13. False negative and false positive findings.

	False negative (n = 19)	False positive (n = 2)	Reference
Spinal fracture	5 (4 %)		Control MDCT
Spinal fracture	1 (1 %)		Review of primary MDCT
Intestinal rupture	3 (2 %)		Laparotomy
Liver laceration	1 (1 %)		Laparotomy
Liver laceration	1 (1 %)		Ultrasound
Rib fracture	2 (2 %)		Chest radiography
Clavicular fracture	1 (1 %)		Chest radiography
Heart contusion	1 (1 %)		Autopsy
Hemoperitoneum	1 (1 %)		Ultrasound
Intestinal contusion	1 (1 %)		Laparotomy
Pancreatic contusion	1 (1 %)		Laboratory findings
Skull fracture	1 (1 %)		Autopsy
Intestinal perforation		1 (1 %)	Laparotomy
Spleen laceration		1 (1 %)	Laparotomy

5.3 Reliability of computed tomography in rapid screening of multiple traumas (II)

Among the 40 patients in this study, nine had no findings and 31 had at least one finding consistent with trauma. Correctly diagnosed findings were seen in 141 compartments (88%) in 25 patients (62%), including 24 true positive findings and 117 true negative findings (Table 14). Misdiagnosed findings were seen in 19 compartments (12%) in 15 patients (38%) (Table 15).

Four interventions were performed immediately after the MDCT scanning, and these patients were transferred directly to the operation or angiography suite. These interventions included one fixation of thoracic spine fractures, two laparotomies, and one angiography and embolization due to continuous bleeding from the internal pudendal arteries. There were no misdiagnosed injuries in these cases. None of the findings missed in the initial structured evaluation from the scanner's console required immediate intervention, and no deterioration in patient condition due to diagnostic delay was observed.

Table 14. Number of true and false findings by compartments as evaluated from the scanner's screen, and sensitivity (Se) and specificity (Sp) of the evaluation.

Compartment	True positive	True negative	False positive	False negative	Se	Sp
Thorax*	8 (20 %)	22 (55 %)	2 (5 %)	8 (20 %)	0.50	0.92
Abdomen	6 (15%)	31 (77.5%)	1 (2.5%)	2 (5%)	0.75	0.97
Retro-peritoneum	2 (5%)	37 (92.5%)	0 (0%)	1 (2.5%)	0.67	1.00
Spine and bones	8 (20%)	27 (67.5%)	0 (0%)	5 (12.5%)	0.62	1.00
Total	24 (15%)	117 (73.1%)	3 (1.9%)	16 (10%)	0.60	0.98

*Thorax includes the ribs

Table 15. Misdiagnosed false negative (FN) and false positive (FP) findings in 15 patients.

	FN	FP
Thorax	8	2
Abdomen	2	1
Retroperitoneum	1	0
Spine	5	0

5.4 Effect of computed tomography on the treatment of ICU patients (III)

During the study period there were a total of 619 ICU admissions, and 343 of them lasted more than 48 h. Sixty-four of these patients (19%) underwent prospectively 82 MDCT examinations covering altogether 154 anatomical areas. Fifty of the 82 (61%) examinations resulted in a new treatment intervention directly or after additional examinations. Bronchoscopy and surgical biopsy were the most common additional examinations. Eight patients underwent two and one patient three changes in treatment, which means altogether 60 changes in treatment were made. Surgical intervention was the most frequent intervention (22/60), followed by percutaneous intervention (16/60) and a change in antimicrobial treatment (15/60) (Table 16). Laparotomy was the most frequently performed surgical intervention (15/22), followed by abscess drainage (4/22) and thoracotomy or thoracoscopy (3/22). The following percutaneous interventions were performed: eight pleural drainages, five gallbladder punctures, two abscess drainages, and one maxillary sinus puncture. The frequency of new treatment interventions was similar (63% vs. 61%) both in the 16 MDCT examinations requested by the authors and in the 66 requested by other physicians.

Twenty (24%) MDCT examinations did not lead to changes in treatment or to additional examinations. In these cases the focus of infection or other clinical suspicion was verified, or the examination was otherwise regarded as informative for the requesting physician. Moreover, 12 MDCT examinations (15%) failed to provide any additional information relevant to the patient's treatment.

Thirty-nine percent (60/154) of the scans of individual anatomical areas resulted in a change in treatment; a scan of the thorax in 33%, a scan of the abdomen in 47%, and a scan of other anatomical areas in 47% of the cases (Table 16). Surgical interventions were more common after scans of the abdomen than after scans of the thorax (23% vs. 4% P = 0.001, χ^2 test), while there were no differences in the proportion of scans that led to changes in antimicrobial therapy following abdominal or thoracic scans (9% vs. 11%, P = 0.786, χ^2 test) (Table 16).

Table 16. Change in treatment after 154 scans of different anatomical areas [n (%)].*

Treatment	Total 154	Thorax 73	Abdomen 64	Other anatomical area 17
Surgical intervention	22 (14.3%)	3 (4.1%)	15 (23.4%)	4 (23.5%)
Percutaneous or paranasal intervention	16 (10.4%)	8 (11.0%)	6 (9.4%)	2 (11.8%)
Change in anti-microbial treatment	15 (9.8%)	8 (11.0%)	6 (9.4%)	1 (5.9%)
Withdrawal of active treatment[1]	3 (1.9%)[1]	2 (2.7%)[1]	3 (4.7%)[1]	0
Anticoagulation	2 (1.3%)	2 (2.7%)	0	0
Enhancement of diuresis[2]	1 (0.6%)	1 (1.4%)	0	0
Weaning from mechanical ventilation[3]	1 (0.6%)	0	0	1 (5.9%)
	60/154 (39.0%)	24/73 (32.9%)	30/64 (46.9%)	8/ 17 (47.1%)

*Eight patients underwent two and one patient three changes in treatment

[1]Decision was based on combined thoracic and abdominal findings in two cases

[2]Reason was pulmonary edema, chest radiography was inconclusive due to pneumonia

[3]Followed resolving neck abscess

5.5 Accuracy of computed tomography on AAC (IV)

During the study period of 72 months, 4454 adult patients were admitted to the ICU. A total of 110 of these patients underwent cholecystectomy due to AAC suspected either preoperatively or during the laparotomy. Altogether 43 patients underwent abdominal CT scanning less than 72 hours prior to cholecystectomy. CT scanning and cholecystectomy were performed on the same day on 15 patients. CT scanning was performed on 20 patients on the previous day, on six patients two days, and on two patients three days before cholecystectomy. Indications for the laparotomy were: suspicion of AAC in 17/ 43 (39.5%) patients, suspicion of both colitis and AAC in 6/ 43 (14.0%) patients, and a reason other than AAC in 20/ 43 (46.5%) patients. Eighty-four ICU patients were selected as controls. In 61% of the patients (78/127), the indication to perform CT scanning was to identify a suspected focus of infection; in 31%, to evaluate inconclusive sonographic or plain abdominal radiographic findings (40/127); in 4%, to evaluate a suspected malignant tumor (5/127); and in 3%, to identify traumatic lesions (4/127). CT images were recalled from the digital image archive in 121 cases and read from film in six cases. In one case only non-enhanced CT scanning was performed due to existing acute renal failure.

Based on the operative findings, 8/43 of the gallbladders were regarded as normal, 26/43 presented an edematous GB, and 9/43 presented necrotic AAC. The patients presenting an edematous GB had received higher median doses of oxycodonhydrochlorid (139.2 mg [25th-75th pct 62.6 mg–253.7 mg]) prior to imaging than had the patients with necrotic AAC (44.4 mg [12.0 mg–425.8 mg]), the control patients (33.3 mg [15.5 mg–110.5 mg]), or the patients with a normal GB (10.0 mg [5.0 mg–79.1 mg]), P = 0.027. The doses of propofol or corticosteroidal drugs did not show a statistically significant difference between the study groups.

The SOFA scores of the cardiovascular system were higher in the patients presenting an edematous GB (3.0 [1.0–3.5]) than in the control patients (1.0 [0.0–3.0]), P = 0.009. In addition, the total SOFA scores tended to be higher with the patients presenting an edematous GB (9.0 [7.0–12.0]) than with the control study group (7.0 [4.0–10.0]), P = 0.05. The SAPS II and APACHE II scores were comparable between the study groups.

Totally normal CT scans were obtained from 4% of the patients (5/127), and in 17% of the patients (21/127) there was a lack of any findings localized in or adjacent to the GB. None of these patients presented an edematous GB or necrotic

AAC in the operation. The localized CT findings with both categorical and continuous variables are shown in Table 17. GB wall thickness > 3 mm in the neck, GB width, gas in either the lumen or wall of the GB, and GB wall thickness > 3 mm in the fundus showed statistically the most significant differences between the patient groups, with P-values of 0.009, 0.012, 0.017, and 0.017, respectively. There was no significant correlation between bile density values and length of ICU stay prior to CT scanning. General CT findings (ascites, peritoneal fat edema, and diffuse tissue edema) not localized adjacent to the GB are shown in Table 18.

The highest specificity of the CT findings for necrotic AAC in our series were gas in the GB wall or lumen (99.2%), lack of GB wall enhancement (94.9%), and edema around the GB (92.4%). The sensitivities of these CT findings for necrotic AAC were 11.1%, 37.5%, and 22.2%, respectively.

Table 17. Localized CT Findings in the Study Patients.

Categorical Variables, Positive Findings/ Total Number of Cases (percent)					
CT finding	Control patients	Normal gallbladder	Edematous gallbladder	Necrotic AAC	P-value
Subserosal edema	6/84 (7.1)	0/8	6/26 (23.1)	0/9	0.11
Localized edema around the GB	4/84 (4.8)	2/8 (25.0)	3/26 (11.5)	2/9 (22.2)	0.041
Local fluid around the GB	16/84 (19.0)	1/8 (12.5)	6/26 (23.1)	3/9 (33.3)	0.71
Gas in the lumen/ in the wall of the GB	0/84	1/8 (12.5)	0/26	1/9 (11.1)	0.017
Lack of GB wall enhancement	4/84 (4.8)	1/8 (12.5)	1/26 (3.8)	3/8 (37.5)	0.018
GB wall thickness > 3 mm in the neck	5/84 (6.0)	1/8 (12.5)	7/26 (26.9)	2/8 (25.0)	0.009
GB wall thickness > 3 mm in the fundus	8/84 (9.5)	1/8 (12.5)	9/26 (34.6)	2/8 (25.0)	0.017
GB wall thickness > 3 mm in the body	9/84 (10.7)	1/8 (12.5)	9/26 (34.6)	2/8 (25.0)	0.028

Continuous Variables in the Study Patients, median (25th-75th pct)					
CT finding	Control patients	Normal gallbladder	Edematous gallbladder	Necrotic AAC	P-value
GB length (cm)	9.0 (7.4-10.5)	9.0 (6.9-10.9)	10.2 (8.2-11.0)	10.6 (9.4-11.8)	0.16 [1]
GB width (cm)	3.8 (2.9-4.6)	4.9 (3.6-5.0)	4.2 (3.4-4.9)	4.9 (4.5-5.4)	0.012 [1]
Choledochus width (mm)	5.0 (4.3-6.3)	4.5 (4.0-6.3)	5.3 (4.5-7.0)	5.5 (4.0-6.5)	0.81
Median bile density in the fundus of the GB (HU)	8 (3-16)	1 (-1-3)	16 (8-29)	8 (5-10)	0.10 [2]
Median bile density in the body of the GB (HU)	13 (7-24))	6 (4-8)	22 (12-41)	10 (6-15)	0.044 [2]
Median bile density in the neck of the GB (HU)	18 (12-30)	11 (10-11)	30 (13-41)	18 (9-23)	0.14 [2]

[1] Comparison between control patients and necrotic AAC

[2] Comparison between an edematous gallbladder and necrotic AAC

Table 18. General CT Findings in the Study Patients, Positive findings/ Total number of cases (percent).

CT finding		Control patients	Normal gallbladder	Edematous gallbladder	Necrotic AAC	P-value
Ascites	-	30/84 (35.7)	3/8 (37.5)	6/26 (23.1)	0/9 (0.0)	0.21
	+	28/84 (33.3)	2/8 (25.0)	11/26 (42.3)	4/9 (44.4)	
	++	24/84 (28.6)	2/8 (25.0)	7/26 (26.9)	4/9 (44.4)	
	+++	2/84 (2.4)	1/8 (12.5)	2/26 (7.7)	1/9 (11.1)	
Peritoneal fat edema	-	32/84 (38.1)	3/8 (37.5)	5/26 (19.2)	1/9 (11.1)	0.07
	+	28/84 (33.3)	1/8 (12.5)	7/26 (26.9)	4/9 (44.4)	
	++	21/84 (25.0)	4/8 (50.0)	10/26 (38.5)	2/9 (22.2)	
	+++	3/84 (3.6)	0/8 (0.0)	4/26 (15.4)	2/9 (22.2)	
Diffuse tissue edema	-	14/84 (16.7)	3/8 (37.5)	3/26 (11.5)	1/9 (11.1)	0.48
	+	43/84 (51.2)	4/8 (50.0)	14/26 (53.8)	4/9 (44.4)	
	++	21/84 (25.0)	0/8 (0.0)	5/26 (19.2)	2/9 (22.2)	
	+++	6/84 (7.1)	1/8 (12.5)	4/26 (15.4)	2/9 (22.2)	

- = Not evident

+ = Minimally

++ = Moderately

+++ = Abundantly

6 Discussion

6.1 General aspects of the study

The majority of studies dealing with CT imaging for multiple trauma or polytrauma concentrate on a single organ (e.g. the liver) or a single body compartment (e.g. the thorax). Far less of the literature evaluates CT scanning from the top of the head to the pelvis as an entity in the context of trauma. To a certain extent, the results of a given study are center-specific because of the exploitation of local resources and particular practices (Gralla *et al.* 2005, Rieger *et al.* 2009). As a consequence, it appeared imperative to test our trauma CT protocol against experiences from other centers (studies I and II).

Although there are studies with CT in such conditions as intra-abdominal sepsis, trauma, pulmonary embolism, or adult respiratory distress syndrome, the overall impact of CT on the treatment of general ICU patients is not known (Go *et al.* 2005, Ichikado *et al.* 2006, Voggenreiter *et al.* 2000). In study III the clinical significance of CT scanning for patient care in a mixed medical–surgical ICU was assessed in cases where other imaging modalities (e.g. chest radiography or ultrasonography) failed to provide sufficient information for a diagnosis or a treatment decision.

An edematous gallbladder (GB) is a frequent finding in critically ill patients and should be distinguished from a more severe form of necrotic gallbladder inflammation. Unfortunately, laboratory tests (Pelinka *et al.* 2003) and clinical findings (Laurila *et al.* 2004) have turned out unreliable in predicting necrotic AAC. Furthermore, US has low diagnostic accuracy (Boland *et al.* 2000, Mariat *et al.* 2000, Mirvis *et al.* 1986, Pelinka *et al.* 2003, Puc *et al.* 2002) and cholescintigraphy lacks specificity in AAC (Mirvis *et al.* 1986). Study IV was conducted to clarify the usefulness of CT findings in predicting necrotic AAC in ICU patients.

6.2 Strengths and weaknesses

The Injury Severity Score (ISS) is an established medical score used to assess trauma severity (Baker *et al.* 1974, Copes *et al.* 1988, Salottolo *et al.* 2009). Although the patients in studies I and II were victims of high-energy trauma based on the indications listed by Stene (Appendix, Table 19), ISS scores were not registered. The lack of these data limits the comparability of our data with other trauma series. The absence of a real standard of reference for diagnosis of injuries is also a drawback. Despite the review of follow-up examinations, surgery, and clinical outcome, undetected injuries may still have remained. This is most likely in the cases of minor, and hence clinically silent, injuries.

Study III was an observational study that provided an opportunity to determine the impact of MDCT findings on treatment and clinical decision-making. The multidisciplinary evaluation group assessed prospectively the impact of the MDCT findings on the patient's treatment. This enabled a robust evaluation of the contribution of the CT findings to treatment decisions as well as the need for additional examinations. Neither the reliability of the MDCT findings nor the real importance of negative MDCT findings was evaluated, which is a limitation of the study.

Study IV was the first report of CT findings in acute acalculous cholecystitis (AAC) in critically ill patients that provided surgical operative conformation. The patient material suffering from AAC is one of the largest in an ICU setting. Because of the retrospective nature of the study, the imaging parameters were not uniform. This may have some impact on the consistency of the gallbladder findings.

6.3 Accuracy of CT in assessing blunt multiple trauma patients

Trauma surgeons and physicians treating patients exposed to high-energy trauma face the dilemma of having to perform a rapid but still reliable evaluation of all significant injuries without unnecessarily delaying treatment. Although a reliable physical examination for an abdominal injury has a high negative predictive value (85%), almost half of multiply injured patients have an equivocal physical examination (Schurink *et al.* 1997). A reliable physical examination of patients with a head injury is only feasible in 16% of cases (Schurink *et al.* 1997). Hemodynamically stable patients can be subjected to a diagnostic CT examination (Leidner *et al.* 1998, Philipp *et al.* 2003, Rieger *et al.* 2009, Sampson *et al.* 2006). The high sensitivity (94%), specificity (100%), and accuracy (97%) of CT in patients with high-energy trauma in our study support earlier results.

Our hypothesis was that patients exposed to high-energy trauma would benefit from a CT examination. Ninety-nine patients (74%) had findings consistent with trauma, suggesting that the prevalence of injuries is very high when the criteria of high-energy trauma are fulfilled. However, slightly less negative CT studies were reported in patients with major trauma involving two or more body compartments with an Abbreviated Injury Scale score ≥ 2 (Sampson *et al.* 2006). When victims of a significant mechanism of trauma with no obvious signs of chest or abdominal injury underwent whole body CT examination, overall treatment was changed in 18.9% of the cases (Salim *et al.* 2006). The use of CT with high-energy trauma patients is warranted.

The maximum productivity of MDCT was established in two cases (2%) where the patients had injuries in all five body compartments. A total of 57 of the 133 patients (43%) had injuries in two or more compartments. Thoracic injuries, which were seen in 58 patients (44%), were the most frequent findings in the current study. Because of the vital nature of the thoracic structures, it is obvious that any significant delay in diagnosing these injuries may cause a substantial compromise of prognosis. The sensitivity of CT warrants its use to exclude traumatic aortic injury (Chen *et al.* 2004, Cleverley *et al.* 2002, Demetriades *et al.* 2008, Dyer *et al.* 1999, Melton *et al.* 2004). There were no aortic injuries in this study, nor any indications for follow-up based on conventional aortography. The progression of several findings, mostly accumulation of pleural fluid, was observed in the follow-up. Chest radiography and ultrasound provided enough information about the changes, obviating any need for a tertiary CT survey.

CT is well established as a highly accurate imaging modality for the detection of solid organ injuries, which is in concordance with our results. The accuracy of CT in the diagnosis of gastrointestinal and mesenteric injuries still remains controversial (Atri *et al.* 2008, Elton *et al.* 2005, Holmes *et al.* 2004, Killeen *et al.* 2001). There were three false-negative findings of intestinal rupture in our study. Bowel and mesenteric injuries are a diagnostic challenge, but accurate and reproducible results can be achieved using a variety of CT criteria (Butela *et al.* 2001, Killeen *et al.* 2001). There is no pertinent consensus on the adequacy of oral contrast material for CT in trauma patients (Butela *et al.* 2001, Federle *et al.* 1997, Shreve *et al.* 1999). CT imaging without oral contrast material has shown to compare favorably with CT imaging using oral contrast material (Allen *et al.* 2004, Holmes *et al.* 2004). In our study, the prevalence of intestinal perforation was quite low (2%), indicating that the use of oral contrast material could be limited to abdominal trauma victims. All major injuries of the urinary system and retroperitoneum were correctly diagnosed with MDCT.

Clinical evaluation of the spine is often equivocal, and false-negative findings are frequent in the case of unconscious patients (Schurink *et al.* 1997). CT has proved superior to plain radiography in the detection of spinal injuries. Plain radiographs contribute no additional information, and should not be obtained (Tables 1 and 2). The 2 mm slice thickness used in our MDCT protocol enabled high-quality multiplanar reformatting. As long as the primary data were restored, it was possible to reconstruct images with 2 mm image thickness (3 mm as a default) and 1 mm overlapping (2 mm as a default). Six conservatively treated minor vertebral fractures (5%) were overlooked in this study, presumably because of the wealth of other findings. The high spatial resolution in CT obviates the need for radiography.

The accuracy of examination procedures has to be determined precisely. Whereas false positive diagnoses may cause unnecessary further diagnostic evaluation, false negative diagnoses may be devastating (Scalea & Mirvis 2003). Attractively high specificity of a test may turn out useless if sensitivity remains disappointingly low. Injuries may be missed both in the first survey, i.e. in a rapid physical examination, ultrasonography, and radiography, and in the second survey, i.e. detailed head-to-toe physical examination and CT (Biffl *et al.* 2003, Buduhan & McRitchie 2000, Houshian *et al.* 2002). In our study, follow-up examinations, surgery, and clinical outcome revealed 19 false negative findings and 2 false positive findings, supporting the requirement for a tertiary survey in order to diminish the problem.

6.4 Evaluation of CT images from the scanner's console

In this study, 62% of high-energy trauma patients were correctly diagnosed in a rapid 5-min initial structured evaluation of MDCT images from the scanner's console. The overall sensitivity of the initial structured evaluation from the scanner's console was 60% and specificity 98%. Several findings were missed in 38% of the patients, but these were findings that neither required immediate intervention nor led to an obvious increase in morbidity. All the patients requiring immediate intervention were correctly diagnosed.

This study evaluated the daily practice in our institution equipped with a four-slice MDCT scanner, which is situated in the vicinity of the emergency care unit. In our trauma protocol, the reconstruction time of the whole image data set covering the thorax, abdomen, and pelvis is 5–6 min. Potential extra delay may be caused by image evaluation at a PACS workstation separate from the scanner console, as is the case in our institution. This requires an additional image transfer, which may take several minutes, depending on network capacity and the number of transferred images. In the case of a high-energy trauma patient, every minute gained in the time needed to diagnose life-threatening injuries may be critical. Along with the recent advances in computer technology, the reconstruction time of new 16- or 64-row MDCT scanners is no longer an issue of diagnostic delay, and a rapid initial evaluation of trauma images with new scanners is therefore likely to yield better sensitivity than observed here. The results of the current study may, however, be extrapolated to the evaluation of images in the axial plane with reasonable certainty, regardless of the precision of the scanner technique.

Missed injuries were most frequent in the thoracic compartment, including eight false negative and two false positive findings. The diagnostic delay of these injuries had no obvious impact on patient outcome. Slightly degraded image quality due to the RTIR technique and limitation of axial slices turned out to increase the frequency of missed findings. MDCT and chest radiography were not compared in our study, but earlier works have demonstrated the superiority of CT over chest radiography in detecting chest trauma complications (Guerrero-Lopez *et al.* 2000, Trupka *et al.* 1997).

Helical CT, and especially multi-detector CT, are superior to conventional radiographs in depicting spine fractures (Hauser *et al.* 2003, Rhee *et al.* 2002, Sheridan *et al.* 2003, Wintermark *et al.* 2003). In our study, unstable spine fractures were missed in two patients (5%). It has been shown that abdominal and pelvic single-slice CT without reformatted images fails to diagnose up to 23% of lumbar fractures and 46% of fractures requiring therapy (Rhee *et al.* 2002). In conjunction with our results, this implies that dedicated screening of both high-quality axial slices and reformatted images is essential in order to avoid misdiagnoses of spine fractures.

6.5 Impact of CT on clinical decision-making in critically ill patients

Our results showed that while only one fifth of our patients staying in the ICU more than 48 hours underwent MDCT examination, 85% of the examinations either led to a new treatment intervention or otherwise provided important information confirming previous clinical or radiological suspicions. No significant impairment of renal or cardiorespiratory function during transportation was seen.

In our patient population, the MDCT examination was indispensable, because the requesting physicians considered clinical data and the information of other imaging modalities insufficient for decision-making. Although our setting was not a blinded interventional study, it provided an opportunity to determine the impact of MDCT findings on treatment and clinical decision-making. Whether wider use of MDCT examinations would have had more impact on clinical treatment remains open in this single-center observational study. The purpose of our study was to evaluate whether MDCT examination will change treatment, but not to evaluate the reliability of MDCT findings.

Although abdominal ultrasonography is a safe bedside procedure, certain anatomical areas are difficult to visualize, and their examination can be hampered by wounds, surgical dressings, drains, and the presence of an ileus (Go *et al.* 2005). Because of our clinical practice, only a few abdominal ultrasonographic examinations were performed before the MDCT examinations, because we usually omit the less informative ultrasonography whenever a MDCT examination is planned. For this reason, we could not determine the precise effectiveness of alternative examinations in demonstrating the presence of, for example, pleural fluid. It is important to note that, for instance, pleural drainage or gallbladder puncture could also have been chosen after ultrasonography in some cases if the attending physician had been able to suspect these conditions without the MDCT examination. On the other hand, this fact further underlines the utility of MDCT imaging in ICU patients as a way to resolve ambiguous situations.

In earlier literature the clinical usefulness of scans of different anatomical areas has not been systematically evaluated in a general ICU population. In our study, the MDCT examination led to new treatments or contributed to or supported clinical decision-making as frequently as reported in one study with 16 patients (85% vs. 82.5%) with a single-slice helical CT scanner (Kumta *et al.* 2002). Interestingly, in our study, almost half of the abdominal examinations resulted in a change in treatment, compared with one third of the thoracic examinations. In one prospective study of trauma patients with suspected intra-abdominal sepsis, the initial abdominal CT resulted in a change in the patient's treatment in 58% of the cases, while the follow-up tomography resulted in a corresponding change in 37% of the cases (Velmahos *et al.* 1999). In another study none of the findings resulted in surgical treatment, in five cases an intra-abdominal collection was suspected and one drain was inserted (Kumta *et al.* 2002). The differences between the consequences of CT examinations are presumably due to a different case mix. Our patients were severely ill, with a high median APACHE II score of 22.5 and a relatively long median ICU stay of 9 days.

Our experience with thoracic computed tomography were slightly better than in earlier literature concerning general ICU patients; there were changes in clinical management in 33% of the cases compared with 22–26% (Miller *et al.* 1998, Roddy *et al.* 1981). However, in a specific ICU population, even higher figures have been found; by assessing the efficiency of secondary chest CT in critically ill patients with multiple traumas, chest CT had an overall efficiency of 57% when the therapeutic interventions were based on abnormalities that were seen on CT scans but not evident on chest radiographs (Voggenreiter *et al.* 2000). In our study, 11% of the patients underwent a change in anti-microbial treatment after thoracic CT. This is supported by the literature stating that in an appropriate clinical setting, CT may be either suggestive of an etiology of underlying pulmonary disease or it may help to narrow a list of alternative differential diagnoses (Franquet *et al.* 2003, Hidalgo *et al.* 2003, Kim *et al.* 2003, Lee *et al.* 2003, Wong *et al.* 2004). Taken together, abdominal MDCT examinations seem to be slightly more beneficial than thoracic MDCT examinations in a general ICU population.

Intra-hospital transfer of critically ill patients has been reported to pose major risks, either system based or human based (Beckmann *et al.* 2004). We did not observe any significant adverse events caused by MDCT examinations or transportation from the ICU to the radiology suite when the same ICU team in charge treated the patient during the examinations. Our study supports earlier experience showing that transportation from the ICU to the radiology suite is fairly safe (Szem *et al.* 1995, Velmahos *et al.* 1999). We did not observe any significant adverse events caused by MDCT examinations when our ICU team, i.e. a physician and a nurse, treated the patient during the transportation and examination, and preventive measures against renal toxicity were applied. The availability of a portable CT scanner may offer safe means of obtaining diagnostic imaging studies and obviate a need for intra-hospital patient transfer (McCunn *et al.* 2000). Portable scanners are based on either multiple single-dimension detectors (a traditional MSCT) or a single volumetric flat panel detector (a cone beam CT). However, a cone beam CT produces soft tissue images with decreased quality due to a reduced contrast-to-noise ratio (Rumboldt *et al.* 2009).

6.6 CT findings in acalculous cholecystitis in critically ill patients

Our study is the first report of CT findings in the gallbladder (GB) of critically ill patients that provides a comparison with operative findings. We found that patients with a surgical finding of an edematous GB or necrotic AAC have divergent CT findings. In concordance with previous reports, the CT findings had high specificity but low sensitivity in differential diagnostics of a necrotic GB from other GB conditions. However, a normal GB in CT precluded both an edematous GB and necrotic AAC.

GB abnormalities are frequent in ICU patients (Boland *et al.* 2000) and are considered largely a manifestation of systemic critical illness (Laurila *et al.* 2005) associated with multiple organ dysfunction (Laurila *et al.* 2006). In our study, surgical findings in the GB were divided into two main groups: edematous and necrotic forms. Necrotic AAC may lead to perforation of the GB wall and life-threatening biliary peritonitis. Once the diagnosis has been made, cholecystectomy should be the treatment of choice, since early cholecystectomy has been associated with a very low mortality rate, and cholecystostomy may require secondary cholecystectomy in some patients. AAC complicated by gangrene or perforation is a definite indication for cholecystectomy and cannot be treated by percutaneous drainage (Hamp *et al.* 2009, Laurila *et al.* 2004, Laurila *et al.* 2006). In less severe cases without multiorgan dysfunctions, diagnostic or therapeutic drainage via interventional radiology may be the only treatment needed (Huffman & Schenker 2010).

Our findings suggest that an edematous GB might be more than a precursor of necrotic AAC. If an edematous GB is a less severe stage of the same disease as necrotic AAC, it could be assumed that the CT findings are similar but milder. However, this was not the case. While higher bile density and subserosal edema were associated with an edematous GB, gas in the GB wall was associated with necrotic AAC.

Eighty-three percent of our ICU patients (106/127) presented abnormal findings in the GB or adjacent to the GB. None of the patients presenting edematous or necrotic AAC were lacking localized CT findings. Thus, our findings suggest that patients who have no localized CT findings in the GB or adjacent to the GB are most unlikely to have AAC. The major confusing issue in diagnosing AAC in ICU patients appears to be the frequent prevalence of nonspecific abnormal imaging findings in the GB (Boland *et al.* 2000). Similar to our results, Boland et al. found that 84% of ICU patients had ultrasonographic abnormalities and 57% had up to three abnormalities, but only two out of 44 patients developed AAC. Many of these findings, including GB wall thickening, GB distension, intramural GB lucencies, pericholecystic fluid, GB sludge, and sonographic Murphy’s sign, have also been associated with AAC, but have shown little value in predicting AAC (Boland *et al.* 2000, Puc *et al.* 2002).

In our study population, patients presenting edematous AAC or necrotic AAC had a thickened GB wall (> 3 mm) significantly more frequently than did patients without AAC. However, 75.0% of the cases with necrotic AAC and 65.4% with edematous AAC had a GB wall thickness ≤ 3 mm. Additionally, 9.5% of the control patients and 12.5% of the patients with a normal GB had a GB wall thickness > 3 mm. A GB wall thickness of more than 3–4 mm has been considered a major criterion of AAC in both sonography and CT study reports (Bennett *et al.* 2002, Boland *et al.* 2000, Mariat *et al.* 2000, Mirvis *et al.* 1986, Pelinka *et al.* 2003, Puc *et al.* 2002). Although a thick-walled GB is associated with acute cholecystitis, the finding itself is nonspecific and may be related to such conditions as GB carcinoma, adenomyomatosis, systemic diseases (e.g. liver dysfunction, heart failure, or kidney failure), and extracholecystic inflammation (van Breda Vriesman *et al.* 2007). Due to the non-specificity of GB wall thickness, this measurement can be questioned as a main diagnostic criterion in clinical practice.

Subserosal edema has been introduced as an equivalent of the sonographic halo sign (Mirvis *et al.* 1986). It was seen in 23.1% of our patients with edematous AAC. Interestingly, none of the patients with necrotic AAC or a normal GB showed this feature. Subserosal edema is widely considered a major criterion for imaging diagnostics of AAC (Fidler *et al.* 1996, Kalliafas *et al.* 1998, Mirvis *et al.* 1986). While Mirvis et al. (Mirvis *et al.* 1986) found subserosal edema highly suggestive of AAC, Fidler et al. (Fidler *et al.* 1996) found this positive in only two of their eight patients. Our findings support the latter experience. A low-density halo rim within the GB wall is clearly evident when mucosal layer enhancement serves a bright inner contrast layer against a darker outer wall. Whether this indicates an absence of transmural inflammation still remains unclear.

Our results show that bile density is higher in an edematous GB than in necrotic AAC. Denser bile is often related to GB sludge, which commonly develops in critically ill patients (Ko & Lee 2003). Accordingly, in our series, patients with an abnormal GB received more opioids and had more severe cardiovascular dysfunction than did those without abnormal findings. Due to a lack of correlation between bile density values and length of ICU stay prior to CT scanning, it is obvious that a prolonged ICU stay is not the only reason for increased bile density. Sludge tends to persist while patients are critically ill, but is supposed to resolve as they recover (Ko & Lee 2003).

The most specific CT findings of necrotic AAC in our series were gas in the GB wall or lumen, lack of GB wall enhancement, and edema around the GB (100.0%, 94.9%, and 92.4%, respectively). Still, all of these findings had poor sensitivity (11.1%, 37.5%, and 22.2%, respectively). Gas in the GB wall or lumen, an irregular or absent gallbladder wall, intraluminal membranes, pericholecystic abscess, and a lack of GB wall enhancement are postulated as specific CT findings of acute cholecystitis complicated by gangrene (Bennett *et al.* 2002). A reliable preoperative diagnosis of gangrenous AAC would be desirable in order to allow urgent surgical cholecystectomy. On the other hand, an unnecessary invasive procedure may be devastating for a critically ill patient. There is evidence that symptomatic patients without gallstones may benefit from cholecystectomy if a hepatobiliary iminodiacetic acid scan (also referred to as cholescintigraphy) shows positive results (Mahid *et al.* 2009).

A possible source of inaccuracy in this study is the time lag between the CT scan and the operation. However, 35/43 patients (81%) underwent CT scanning on the same or previous day as cholecystectomy was performed. Retrospective analysis of the operative findings may hamper the most appropriate information, as well. Furthermore, the golden standard of ACC diagnosis is lacking. Some of our patients could have had AAC that was cured without needing surgical intervention. The clinical course of AAC is also incompletely understood. We have previously shown that histological changes also exist in the edematous form of AAC, but it is not known whether edema generally precedes necrosis (Laurila *et al.* 2005). Our findings suggest, albeit indirectly, that gallbladder necrosis often develops without preceding gallbladder edema.

6.7 Generalization of the results

Inevitably, the results in this study are center-specific because of the exploitation of local resources and particular practices. However, e.g. the imaging protocols and indications for imaging examinations in our institution are based on the literature and references from international conferences. Therefore, our results can be reiterated and verified by other institutions.

6.8 Clinical impacts of the study

CT, and recently MDCT, have proven invaluable tools in imaging diagnostics of multiple traumas and diseases of critically ill patients. Since a transfer of both

ICU patients and patients with multiple traumas is potentially hazardous, the vicinity of the MDCT suite is critical for successful exploitation of this resource. This fact should be taken account when new CT scanners are installed in hospitals. Our study also suggests that it is also vital to know when CT may provide extra help in patient treatment dilemmas.

6.9 Future aspects

Because of the rapid technical evolution of MDCT scanners, the limitations seen during the planning of the current studies have already been overcome. For instance, the reconstruction time of the whole set of whole-body images is no longer a major issue. However, the potential advantage of the most advanced MDCT technology has to be determined by means of prospective controlled trials. Further studies will be necessary to identify trauma patients who will benefit from whole-body MDCT screening in the early phase of multiple trauma care. In addition, the role of CEUS in the detection of abdominal solid organ injuries needs to be confirmed in larger prospective trials. To optimize the advantages of CT, refinement of the indications for CT scanning is needed.

7 Conclusions

1. MDCT is an accurate examination of blunt multiple trauma patients. Decisions concerning treatment may be based on MDCT with a reasonable level of certainty. However, similar to the literature, bowel and mesenteric injuries remain a diagnostic challenge.
2. A rapid 5-min initial structured evaluation of MDCT images from the scanner's console using three different window settings enables diagnosis of potential life-threatening injuries in high-energy trauma patients. However, dedicated image evaluation at a workstation capable of multiplanar reformatting is still needed for detection of all injuries and exclusion of, for instance, unstable spine fractures.
3. When the clinical indications are fulfilled, 85% of MDCT examinations either result in new treatment interventions or otherwise significantly contribute to clinical decision-making in the treatment of critically ill patients. Further studies are warranted to determine whether wider use of MDCT examinations in a general ICU population would be justifiable.
4. The frequent prevalence of nonspecific abnormal imaging findings in the GB of ICU patients limits the diagnostic value of CT scanning. When the GB appears totally normal in CT images, the probability of any surgical finding in the GB is low. The thickness of the GB wall cannot be regarded as a diagnostic criterion of necrotic AAC. The presence of gas in the GB wall or lumen and the lack of GB wall enhancement are suggestive of necrotic AAC. The sensitivity of these findings is, however, poor.

References

Albrecht RM, Kingsley D, Schermer CR, Demarest GB, Benzel EC & Hart BL (2001) Evaluation of cervical spine in intensive care patients following blunt trauma. World J Surg 25(8): 1089–1096.

Alkadhi H, Wildermuth S, Marincek B & Boehm T (2004) Accuracy and time efficiency for the detection of thoracic cage fractures: volume rendering compared with transverse computed tomography images. J Comput Assist Tomogr 28(3): 378–385.

Allen TL, Cummins BF, Bonk RT, Harker CP, Handrahan DL & Stevens MH (2005) Computed tomography without oral contrast solution for blunt diaphragmatic injuries in abdominal trauma. Am J Emerg Med 23(3): 253–258.

Allen TL, Mueller MT, Bonk RT, Harker CP, Duffy OH & Stevens MH (2004) Computed tomographic scanning without oral contrast solution for blunt bowel and mesenteric injuries in abdominal trauma. J Trauma 56(2): 314–322.

Ambrose J & Hounsfield G (1973) Computerized transverse axial tomography. Br J Radiol 46(542): 148–149.

Antevil JL, Sise MJ, Sack DI, Kidder B, Hopper A & Brown CV (2006) Spiral computed tomography for the initial evaluation of spine trauma: A new standard of care? J Trauma 61(2): 382–387.

Atri M, Hanson JM, Grinblat L, Brofman N, Chughtai T & Tomlinson G (2008) Surgically important bowel and/or mesenteric injury in blunt trauma: accuracy of multidetector CT for evaluation. Radiology 249(2): 524–533.

Bailey SH, Shapiro SB, Mone MC, Saffle JR, Morris SE & Barton RG (2000) Is immediate chest radiograph necessary after central venous catheter placement in a surgical intensive care unit? Am J Surg 180(6): 517–521.

Bailitz J, Starr F, Beecroft M, Bankoff J, Roberts R, Bokhari F, Joseph K, Wiley D, Dennis A, Gilkey S, Erickson P, Raksin P & Nagy K (2009) CT should replace three-view radiographs as the initial screening test in patients at high, moderate, and low risk for blunt cervical spine injury: a prospective comparison. J Trauma 66(6): 1605–1609.

Baker SP, O'Neill B, Haddon W Jr & Long WB (1974) The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. J Trauma 14(3): 187–196.

Ball CG, Kirkpatrick AW, Laupland KB, Fox DI, Nicolaou S, Anderson IB, Hameed SM, Kortbeek JB, Mulloy RR, Litvinchuk S & Boulanger BR (2005) Incidence, risk factors, and outcomes for occult pneumothoraces in victims of major trauma. J Trauma 59(4): 917–924.

Ball CG, Ranson K, Dente CJ, Feliciano DV, Laupland KB, Dyer D, Inaba K, Trottier V, Datta I & Kirkpatrick AW (2009) Clinical predictors of occult pneumothoraces in severely injured blunt polytrauma patients: A prospective observational study. Injury 40(1): 44–47.

Barkhausen J, Stoblen F, Dominguez-Fernandez E, Henseke P & Muller RD (1999) Impact of CT in patients with sepsis of unknown origin. Acta Radiol 40(5): 552–555.

Beckmann U, Gillies DM, Berenholtz SM, Wu AW & Pronovost P (2004) Incidents relating to the intra-hospital transfer of critically ill patients. An analysis of the reports submitted to the Australian Incident Monitoring Study in Intensive Care. Intensive Care Med 30(8): 1579–1585.

Bennett GL, Rusinek H, Lisi V, Israel GM, Krinsky GA, Slywotzky CM & Megibow A (2002) CT findings in acute gangrenous cholecystitis. AJR Am J Roentgenol 178(2): 275–281.

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

Bercault N, Wolf M, Runge I, Fleury JC & Boulain T (2005) Intrahospital transport of critically ill ventilated patients: a risk factor for ventilator-associated pneumonia–a matched cohort study. Crit Care Med 33(11): 2471–2478.

Besenski N (2002) Traumatic injuries: imaging of head injuries. Eur Radiol 12(6): 1237–1252.

Biffl WL, Cothren CC, Moore EE, Kozar R, Cocanour C, Davis JW, McIntyre RC Jr, West MA & Moore FA (2009) Western Trauma Association critical decisions in trauma: screening for and treatment of blunt cerebrovascular injuries. J Trauma 67(6): 1150–1153.

Biffl WL, Egglin T, Benedetto B, Gibbs F & Cioffi WG (2006) Sixteen-slice computed tomographic angiography is a reliable noninvasive screening test for clinically significant blunt cerebrovascular injuries. J Trauma 60(4): 745–751.

Biffl WL, Harrington DT & Cioffi WG (2003) Implementation of a tertiary trauma survey decreases missed injuries. J Trauma 54(1): 38–43.

Biffl WL, Ray CE Jr, Moore EE, Franciose RJ, Aly S, Heyrosa MG, Johnson JL & Burch JM (2002) Treatment-related outcomes from blunt cerebrovascular injuries: importance of routine follow-up arteriography. Ann Surg 235(5): 699–706.

Boland GW, Slater G, Lu DS, Eisenberg P, Lee MJ & Mueller PR (2000) Prevalence and significance of gallbladder abnormalities seen on sonography in intensive care unit patients. AJR Am J Roentgenol 174(4): 973–977.

Bouhemad B, Liu ZH, Arbelot C, Zhang M, Ferarri F, Le-Guen M, Girard M, Lu Q & Rouby JJ (2010) Ultrasound assessment of antibiotic-induced pulmonary reaeration in ventilator-associated pneumonia. Crit Care Med 38(1): 84–92.

Bozeman C, Carver B, Zabari G, Caldito G & Venable D (2004) Selective operative management of major blunt renal trauma. J Trauma 57(2): 305–309.

Brainsky A, Fletcher RH, Glick HA, Lanken PN, Williams SV & Kundel HL (1997) Routine portable chest radiographs in the medical intensive care unit: effects and costs. Crit Care Med 25(5): 801–805.

Buduhan G & McRitchie DI (2000) Missed injuries in patients with multiple trauma. J Trauma 49(4): 600–605.

Burks DW, Mirvis SE & Shanmuganathan K (1992) Acute adrenal injury after blunt abdominal trauma: CT findings. AJR Am J Roentgenol 158(3): 503–507.

Busch M (2006) Portable ultrasound in pre-hospital emergencies: a feasibility study. Acta Anaesthesiol Scand 50(6): 754–758.

Butela ST, Federle MP, Chang PJ, Thaete FL, Peterson MS, Dorvault CJ, Hari AK, Soni S, Branstetter BF, Paisley KJ & Huang LF (2001) Performance of CT in detection of bowel injury. AJR Am J Roentgenol 176(1): 129–135.

Catalano O, Aiani L, Barozzi L, Bokor D, De Marchi A, Faletti C, Maggioni F, Montanari N, Orlandi PE, Siani A, Sidhu PS, Thompson PK, Valentino M, Ziosi A & Martegani A (2009) CEUS in abdominal trauma: multi-center study. Abdom Imaging 34(2): 225–234.

Chahine-Malus N, Stewart T, Lapinsky SE, Marras T, Dancey D, Leung R & Mehta S (2001) Utility of routine chest radiographs in a medical-surgical intensive care unit: a quality assurance survey. Crit Care 5(5): 271–275.

Chan DP, Abujudeh HH, Cushing GL Jr & Novelline RA (2006) CT cystography with multiplanar reformation for suspected bladder rupture: experience in 234 cases. AJR Am J Roentgenol 187(5): 1296–1302.

Chastre J, Trouillet JL, Vuagnat A, Joly-Guillou ML, Clavier H, Dombret MC & Gibert C (1998) Nosocomial pneumonia in patients with acute respiratory distress syndrome. Am J Respir Crit Care Med 157(4 Pt 1): 1165–1172.

Chen MM, Coakley FV, Kaimal A & Laros RK Jr (2008) Guidelines for computed tomography and magnetic resonance imaging use during pregnancy and lactation. Obstet Gynecol 112(2 Pt 1): 333–340.

Chen MY, Miller PR, McLaughlin CA, Kortesis BG, Kavanagh PV & Dyer RB (2004) The trend of using computed tomography in the detection of acute thoracic aortic and branch vessel injury after blunt thoracic trauma: single-center experience over 13 years. J Trauma 56(4): 783–785.

Clec'h C, Simon P, Hamdi A, Hamza L, Karoubi P, Fosse JP, Gonzalez F, Vincent F & Cohen Y (2008) Are daily routine chest radiographs useful in critically ill, mechanically ventilated patients? A randomized study. Intensive Care Med 34(2): 264–270.

Cleverley JR, Barrie JR, Raymond GS, Primack SL & Mayo JR (2002) Direct findings of aortic injury on contrast-enhanced CT in surgically proven traumatic aortic injury: a multi-centre review. Clin Radiol 57(4): 281–286.

Como JJ, Diaz JJ, Dunham CM, Chiu WC, Duane TM, Capella JM, Holevar MR, Khwaja KA, Mayglothling JA, Shapiro MB & Winston ES (2009) Practice management guidelines for identification of cervical spine injuries following trauma: update from the eastern association for the surgery of trauma practice management guidelines committee. J Trauma 67(3): 651–659.

Como JJ, Thompson MA, Anderson JS, Shah RR, Claridge JA, Yowler CJ & Malangoni MA (2007) Is magnetic resonance imaging essential in clearing the cervical spine in obtunded patients with blunt trauma? J Trauma 63(3): 544–549.

Cook D, Crowther M, Meade M, Rabbat C, Griffith L, Schiff D, Geerts W & Guyatt G (2005) Deep venous thrombosis in medical-surgical critically ill patients: prevalence, incidence, and risk factors. Crit Care Med 33(7): 1565–1571.

Copes WS, Champion HR, Sacco WJ, Lawnick MM, Keast SL & Bain LW (1988) The Injury Severity Score revisited. J Trauma 28(1): 69–77.
D'Alise MD, Benzel EC & Hart BL (1999) Magnetic resonance imaging evaluation of the cervical spine in the comatose or obtunded trauma patient. J Neurosurg 91(1 Suppl): 54–59.
Dalla Palma L, Stacul F, Meduri S & Geitung JT (2000) Relationships between radiologists and clinicians: results from three surveys. Clin Radiol 55(8): 602–605.
Davis PC & Expert Panel on Neurologic Imaging (2007) Head trauma. AJNR Am J Neuroradiol 28(8): 1619–1621.
Dawson P (2004) Patient dose in multislice CT: why is it increasing and does it matter? Br J Radiol 77 Spec No 1: S10–13.
de Knegt C, Meylaerts SA & Leenen LP (2008) Applicability of the trimodal distribution of trauma deaths in a Level I trauma centre in the Netherlands with a population of mainly blunt trauma. Injury 39(9): 993–1000.
de Moya MA, Seaver C, Spaniolas K, Inaba K, Nguyen M, Veltman Y, Shatz D, Alam HB & Pizano L (2007) Occult pneumothorax in trauma patients: development of an objective scoring system. J Trauma 63(1): 13–17.
Deck AJ, Shaves S, Talner L & Porter JR (2001) Current experience with computed tomographic cystography and blunt trauma. World J Surg 25(12): 1592–1596.
Demetriades D, Kimbrell B, Salim A, Velmahos G, Rhee P, Preston C, Gruzinski G & Chan L (2005) Trauma deaths in a mature urban trauma system: is "trimodal" distribution a valid concept? J Am Coll Surg 201(3): 343–348.
Demetriades D, Murray J, Charalambides K, Alo K, Velmahos G, Rhee P & Chan L (2004) Trauma fatalities: time and location of hospital deaths. J Am Coll Surg 198(1): 20–26.
Demetriades D, Velmahos GC, Scalea TM, Jurkovich GJ, Karmy-Jones R, Teixeira PG, Hemmila MR, O'Connor JV, McKenney MO, Moore FO, London J, Singh MJ, Spaniolas K, Keel M, Sugrue M, Wahl WL, Hill J, Wall MJ, Moore EE, Lineen E, Margulies D, Malka V & Chan LS (2008) Diagnosis and treatment of blunt thoracic aortic injuries: changing perspectives. J Trauma 64(6): 1415–1418.
Desai SR, Wells AU, Rubens MB, Evans TW & Hansell DM (1999) Acute respiratory distress syndrome: CT abnormalities at long-term follow-up. Radiology 210(1): 29–35.
Deunk J, Brink M, Dekker HM, Kool DR, van Kuijk C, Blickman JG, van Vugt AB & Edwards MJ (2009) Routine versus selective computed tomography of the abdomen, pelvis, and lumbar spine in blunt trauma: a prospective evaluation. J Trauma 66(4): 1108–1117.
Diaz JJ Jr, Cullinane DC, Altman DT, Bokhari F, Cheng JS, Como J, Gunter O, Holevar M, Jerome R, Kurek SJ Jr, Lorenzo M, Mejia V, Miglietta M, O'Neill PJ, Rhee P, Sing R, Streib E, Vaslef S & EAST Practice Management Guideline Committee (2007) Practice management guidelines for the screening of thoracolumbar spine fracture. J Trauma 63(3): 709–718.
Diaz JJ Jr, Gillman C, Morris JA Jr, May AK, Carrillo YM & Guy J (2003) Are five-view plain films of the cervical spine unreliable? A prospective evaluation in blunt trauma patients with altered mental status. J Trauma 55(4): 658–663.

Dissanaike S, Shalhub S & Jurkovich GJ (2008) The evaluation of pneumomediastinum in blunt trauma patients. J Trauma 65(6): 1340–1345.
Dyer DS, Moore EE, Mestek MF, Bernstein SM, Ikle DN, Durham JD, Heinig MJ, Russ PD, Symonds DL, Kumpe DA, Roe EJ, Honigman B, McIntyre RC Jr & Eule J Jr (1999) Can chest CT be used to exclude aortic injury? Radiology 213(1): 195–202.
Edwards NM, Fabian TC, Claridge JA, Timmons SD, Fischer PE & Croce MA (2007) Antithrombotic therapy and endovascular stents are effective treatment for blunt carotid injuries: results from longterm followup. J Am Coll Surg 204(5): 1007–1013.
Ekeh AP, Saxe J, Walusimbi M, Tchorz KM, Woods RJ, Anderson HL 3rd & McCarthy MC (2008) Diagnosis of blunt intestinal and mesenteric injury in the era of multidetector CT technology–are results better? J Trauma 65(2): 354–359.
Ellis JD & Mayo JR (2007) Computed tomography evaluation of traumatic rupture of the thoracic aorta: an outcome study. Can Assoc Radiol J 58(1): 22–26.
Elmali M, Baydin A, Nural MS, Arslan B, Ceyhan M & Gurmen N (2007) Lung parenchymal injury and its frequency in blunt thoracic trauma: the diagnostic value of chest radiography and thoracic CT. Diagn Interv Radiol 13(4): 179–182.
Elton C, Riaz AA, Young N, Schamschula R, Papadopoulos B & Malka V (2005) Accuracy of computed tomography in the detection of blunt bowel and mesenteric injuries. Br J Surg 92(8): 1024–1028.
Espinosa JA & Nolan TW (2000) Reducing errors made by emergency physicians in interpreting radiographs: longitudinal study. BMJ 320(7237): 737–740.
Exadaktylos AK, Sclabas GM, Smolka K, Rahal A, Andres RH, Zimmermann H & Iizuka T (2005) The value of computed tomographic scanning in the diagnosis and management of orbital fractures associated with head trauma: a prospective, consecutive study at a level I trauma center. J Trauma 58(2): 336–341.
Fabian TC, Patton JH Jr, Croce MA, Minard G, Kudsk KA & Pritchard FE (1996) Blunt carotid injury. Importance of early diagnosis and anticoagulant therapy. Ann Surg 223(5): 513–522.
Fakhry SM, Brownstein M, Watts DD, Baker CC & Oller D (2000) Relatively short diagnostic delays (<8 hours) produce morbidity and mortality in blunt small bowel injury: an analysis of time to operative intervention in 198 patients from a multicenter experience. J Trauma 48(3): 408–414.
Fakhry SM, Watts DD, Luchette FA & EAST Multi-Institutional Hollow Viscus Injury Research Group (2003) Current diagnostic approaches lack sensitivity in the diagnosis of perforated blunt small bowel injury: analysis from 275,557 trauma admissions from the EAST multi-institutional HVI trial. J Trauma 54(2): 295–306.
Fang JF, Wong YC, Lin BC, Hsu YP & Chen MF (2006a) The CT risk factors for the need of operative treatment in initially hemodynamically stable patients after blunt hepatic trauma. J Trauma 61(3): 547–553.
Fang JF, Wong YC, Lin BC, Hsu YP & Chen MF (2006b) Usefulness of multidetector computed tomography for the initial assessment of blunt abdominal trauma patients. World J Surg 30(2): 176–182.

Federle MP, Yagan N, Peitzman AB & Krugh J (1997) Abdominal trauma: use of oral contrast material for CT is safe. Radiology 205(1): 91–93.

Fidler J, Paulson EK & Layfield L (1996) CT evaluation of acute cholecystitis: findings and usefulness in diagnosis. AJR Am J Roentgenol 166(5): 1085–1088.

Franquet T, Lee KS & Muller NL (2003) Thin-section CT findings in 32 immunocompromised patients with cytomegalovirus pneumonia who do not have AIDS. AJR Am J Roentgenol 181(4): 1059–1063.

Gaarder C, Kroepelien CF, Loekke R, Hestnes M, Dormage JB & Naess PA (2009) Ultrasound performed by radiologists-confirming the truth about FAST in trauma. J Trauma 67(2): 323–327.

Gale SC, Gracias VH, Reilly PM & Schwab CW (2005) The inefficiency of plain radiography to evaluate the cervical spine after blunt trauma. J Trauma 59(5): 1121–1125.

Gatt ME, Spectre G, Paltiel O, Hiller N & Stalnikowicz R (2003) Chest radiographs in the emergency department: is the radiologist really necessary? Postgrad Med J 79(930): 214–217.

Gattinoni L, Mascheroni D, Torresin A, Marcolin R, Fumagalli R, Vesconi S, Rossi GP, Rossi F, Baglioni S & Bassi F (1986) Morphological response to positive end expiratory pressure in acute respiratory failure. Computerized tomography study. Intensive Care Med 12(3): 137–142.

Go HL, Baarslag HJ, Vermeulen H, Lameris JS & Legemate DA (2005) A comparative study to validate the use of ultrasonography and computed tomography in patients with post-operative intra-abdominal sepsis. Eur J Radiol 54(3): 383–387.

Gonzales DA, Norsworthy KJ, Kern SJ, Banks S, Sieving PC, Star RA, Natanson C & Danner RL (2007) A meta-analysis of N-acetylcysteine in contrast-induced nephrotoxicity: unsupervised clustering to resolve heterogeneity. BMC Med 5: 32.

Gor DM, Kirsch CF, Leen J, Turbin R & Von Hagen S (2001) Radiologic differentiation of intraocular glass: evaluation of imaging techniques, glass types, size, and effect of intraocular hemorrhage. AJR Am J Roentgenol 177(5): 1199–1203.

Graat ME, Choi G, Wolthuis EK, Korevaar JC, Spronk PE, Stoker J, Vroom MB & Schultz MJ (2006) The clinical value of daily routine chest radiographs in a mixed medical-surgical intensive care unit is low. Crit Care 10(1): R11.

Gralla J, Spycher F, Pignolet C, Ozdoba C, Vock P & Hoppe H (2005) Evaluation of a 16-MDCT scanner in an emergency department: initial clinical experience and workflow analysis. AJR Am J Roentgenol 185(1): 232–238.

Grande CM & Stene JK (1991) Mechanisms of injury: Etiologies of trauma. In: Stene JK & Grande CM (eds) Trauma anesthesia. Baltimore, Williams & Wilkins: 37–63.

Griffen MM, Frykberg ER, Kerwin AJ, Schinco MA, Tepas JJ, Rowe K & Abboud J (2003) Radiographic clearance of blunt cervical spine injury: plain radiograph or computed tomography scan? J Trauma 55(2): 222–226.

Gruen RL, Jurkovich GJ, McIntyre LK, Foy HM & Maier RV (2006) Patterns of errors contributing to trauma mortality: lessons learned from 2,594 deaths. Ann Surg 244(3): 371–380.

Guerrero-Lopez F, Vazquez-Mata G, Alcazar-Romero PP, Fernandez-Mondejar E, Aguayo-Hoyos E & Linde-Valverde CM (2000) Evaluation of the utility of computed tomography in the initial assessment of the critical care patient with chest trauma. Crit Care Med 28(5): 1370–1375.

Hall JB, White SR & Karrison T (1991) Efficacy of daily routine chest radiographs in intubated, mechanically ventilated patients. Crit Care Med 19(5): 689–693.

Halvorsen RA (2008) Which study when? Iodinated contrast-enhanced CT versus gadolinium-enhanced MR imaging. Radiology 249(1): 9–15.

Hamp T, Fridrich P, Mauritz W, Hamid L & Pelinka LE (2009) Cholecystitis after trauma. J Trauma 66(2): 400–406.

Handolin L, Leppaniemi A, Vihtonen K, Lakovaara M & Lindahl J (2006) Finnish Trauma Audit 2004: current state of trauma management in Finnish hospitals. Injury 37(7): 622–625.

Harris TJ, Blackmore CC, Mirza SK & Jurkovich GJ (2008) Clearing the cervical spine in obtunded patients. Spine (Phila Pa 1976) 33(14): 1547–1553.

Hashem R, Evans CC, Farrokhyar F & Kahnamoui K (2009) Plain radiography does not add any clinically significant advantage to multidetector row computed tomography in diagnosing cervical spine injuries in blunt trauma patients. J Trauma 66(2): 423–428.

Hauser CJ, Visvikis G, Hinrichs C, Eber CD, Cho K, Lavery RF & Livingston DH (2003) Prospective validation of computed tomographic screening of the thoracolumbar spine in trauma. J Trauma 55(2): 228–234.

Haveman JW, Gansevoort RT, Bongaerts AH & Nijsten MW (2006) Low incidence of nephropathy in surgical ICU patients receiving intravenous contrast: a retrospective analysis. Intensive Care Med 32(8): 1199–1205.

Hayashino Y, Goto M, Noguchi Y & Fukui T (2005) Ventilation-perfusion scanning and helical CT in suspected pulmonary embolism: meta-analysis of diagnostic performance. Radiology 234(3): 740–748.

Haydel MJ, Preston CA, Mills TJ, Luber S, Blaudeau E & DeBlieux PM (2000) Indications for computed tomography in patients with minor head injury. N Engl J Med 343(2): 100–105.

Hayden GE & Wrenn KW (2009) Chest radiograph vs. computed tomography scan in the evaluation for pneumonia. J Emerg Med 36(3): 266–270.

Hendrikse KA, Gratama JW, Hove W, Rommes JH, Schultz MJ & Spronk PE (2007) Low value of routine chest radiographs in a mixed medical-surgical ICU. Chest 132(3): 823–828.

Hidalgo A, Falco V, Mauleon S, Andreu J, Crespo M, Ribera E, Pahissa A & Caceres J (2003) Accuracy of high-resolution CT in distinguishing between Pneumocystis carinii pneumonia and non- Pneumocystis carinii pneumonia in AIDS patients. Eur Radiol 13(5): 1179–1184.

Hirsch DR, Ingenito EP & Goldhaber SZ (1995) Prevalence of deep venous thrombosis among patients in medical intensive care. JAMA 274(4): 335–337.

Hirsh LF, Duarte L & Wolfson EH (1993) Thoracic spinal cord injury without spine fracture in an adult: case report and literature review. Surg Neurol 40(1): 35–38.

Hogan GJ, Mirvis SE, Shanmuganathan K & Scalea TM (2005) Exclusion of unstable cervical spine injury in obtunded patients with blunt trauma: is MR imaging needed when multi-detector row CT findings are normal? Radiology 237(1): 106–113.

Holmes JF, Offerman SR, Chang CH, Randel BE, Hahn DD, Frankovsky MJ & Wisner DH (2004) Performance of helical computed tomography without oral contrast for the detection of gastrointestinal injuries. Ann Emerg Med 43(1): 120–128.

Horiguchi J, Kiguchi M, Fujioka C, Shen Y, Arie R, Sunasaka K & Ito K (2008) Radiation dose, image quality, stenosis measurement, and CT densitometry using ECG-triggered coronary 64-MDCT angiography: a phantom study. AJR Am J Roentgenol 190(2): 315–320.

Houshian S, Larsen MS & Holm C (2002) Missed injuries in a level I trauma center. J Trauma 52(4): 715–719.

Huber W, Eckel F, Hennig M, Rosenbrock H, Wacker A, Saur D, Sennefelder A, Hennico R, Schenk C, Meining A, Schmelz R, Fritsch R, Weiss W, Hamar P, Heemann U & Schmid RM (2006) Prophylaxis of contrast material-induced nephropathy in patients in intensive care: acetylcysteine, theophylline, or both? A randomized study. Radiology 239(3): 793–804.

Huber W, Jeschke B, Page M, Weiss W, Salmhofer H, Schweigart U, Ilgmann K, Reichenberger J, Neu B & Classen M (2001) Reduced incidence of radiocontrast-induced nephropathy in ICU patients under theophylline prophylaxis: a prospective comparison to series of patients at similar risk. Intensive Care Med 27(7): 1200–1209.

Huber-Wagner S, Lefering R, Qvick LM, Korner M, Kay MV, Pfeifer KJ, Reiser M, Mutschler W, Kanz KG & Working Group on Polytrauma of the German Trauma Society (2009) Effect of whole-body CT during trauma resuscitation on survival: a retrospective, multicentre study. Lancet 373(9673): 1455–1461.

Huffman JL & Schenker S (2010) Acute Acalculous Cholecystitis: A Review. Clin Gastroenterol Hepatol 8(1): 15–22.

Ichikado K, Suga M, Muranaka H, Gushima Y, Miyakawa H, Tsubamoto M, Johkoh T, Hirata N, Yoshinaga T, Kinoshita Y, Yamashita Y & Sasaki Y (2006) Prediction of prognosis for acute respiratory distress syndrome with thin-section CT: validation in 44 cases. Radiology 238(1): 321–329.

Iirola TT, Laaksonen MI, Vahlberg TJ & Palve HK (2006) Effect of physician-staffed helicopter emergency medical service on blunt trauma patient survival and prehospital care. Eur J Emerg Med 13(6): 335–339.

Jensen MB, Sloth E, Larsen KM & Schmidt MB (2004) Transthoracic echocardiography for cardiopulmonary monitoring in intensive care. Eur J Anaesthesiol 21(9): 700–707.

Kalender WA, Seissler W, Klotz E & Vock P (1990) Spiral volumetric CT with single-breath-hold technique, continuous transport, and continuous scanner rotation. Radiology 176(1): 181–183.

Kalliafas S, Ziegler DW, Flancbaum L & Choban PS (1998) Acute acalculous cholecystitis: incidence, risk factors, diagnosis, and outcome. Am Surg 64(5): 471–475.

Katayama H, Yamaguchi K, Kozuka T, Takashima T, Seez P & Matsuura K (1990) Adverse reactions to ionic and nonionic contrast media. A report from the Japanese Committee on the Safety of Contrast Media. Radiology 175(3): 621–628.

Katzberg RW & Barrett BJ (2007) Risk of iodinated contrast material–induced nephropathy with intravenous administration. Radiology 243(3): 622–628.

Kay J, Chow WH, Chan TM, Lo SK, Kwok OH, Yip A, Fan K, Lee CH & Lam WF (2003) Acetylcysteine for prevention of acute deterioration of renal function following elective coronary angiography and intervention: a randomized controlled trial. JAMA 289(5): 553–558.

Kelly AM, Patel S, Carlos RC, Cronin P & Kazerooni EA (2006) Multidetector row CT pulmonary angiography and indirect venography for the diagnosis of venous thromboembolic disease in intensive care unit patients. Acad Radiol 13(4): 486–495.

Kiljunen T (2008) Patient doses in ct, dental cone beam ct and projection radiography in Finland, with emphasis on paediatric patients. PhD thesis. University of Helsinki, Faculty of Science, Department of Physics. Helsinki, Edita Prima Oy.

Killeen KL, Shanmuganathan K, Poletti PA, Cooper C & Mirvis SE (2001) Helical computed tomography of bowel and mesenteric injuries. J Trauma 51(1): 26–36.

Kim PK, Gracias VH, Maidment AD, O'Shea M, Reilly PM & Schwab CW (2004) Cumulative radiation dose caused by radiologic studies in critically ill trauma patients. J Trauma 57(3): 510–514.

Kim SJ, Lee KS, Ryu YH, Yoon YC, Choe KO, Kim TS & Sung KJ (2003) Reversed halo sign on high-resolution CT of cryptogenic organizing pneumonia: diagnostic implications. AJR Am J Roentgenol 180(5): 1251–1254.

Klingenbeck-Regn K, Schaller S, Flohr T, Ohnesorge B, Kopp AF & Baum U (1999) Subsecond multi-slice computed tomography: basics and applications. Eur J Radiol 31(2): 110–124.

Ko CW & Lee SP (2003) Gastrointestinal disorders of the critically ill. Biliary sludge and cholecystitis. Best Pract Res Clin Gastroenterol 17(3): 383–396.

Koivikko MP & Koskinen SK (2008) MRI of cervical spine injuries complicating ankylosing spondylitis. Skeletal Radiol 37(9): 813–819.

Koizumi M, Ueda Y, Iida J, Matsuyama E, Yoshikawa T, Takakura Y, Hirai T & Murakami J (2002) Upper thoracic spinal cord injury without vertebral bony lesion: a report of two cases. Spine (Phila Pa 1976) 27(21): E467–470.

Kollef MH, Von Harz B, Prentice D, Shapiro SD, Silver P, St John R & Trovillion E (1997) Patient transport from intensive care increases the risk of developing ventilator-associated pneumonia. Chest 112(3): 765–773.

Krivopal M, Shlobin OA & Schwartzstein RM (2003) Utility of daily routine portable chest radiographs in mechanically ventilated patients in the medical ICU. Chest 123(5): 1607–1614.

Kroft LJ, de Roos A & Geleijns J (2007) Artifacts in ECG-synchronized MDCT coronary angiography. AJR Am J Roentgenol 189(3): 581–591.

Kroner A, Binnekade JM, Graat ME, Vroom MB, Stoker J, Spronk PE & Schultz MJ (2008) On-demand rather than daily-routine chest radiography prescription may change neither the number nor the impact of chest computed tomography and ultrasound studies in a multidisciplinary intensive care unit. Anesthesiology 108(1): 40–45.

Kuan JK, Wright JL, Nathens AB, Rivara FP, Wessells H & American Association for the Surgery of Trauma (2006) American Association for the Surgery of Trauma Organ Injury Scale for kidney injuries predicts nephrectomy, dialysis, and death in patients with blunt injury and nephrectomy for penetrating injuries. J Trauma 60(2): 351–356.

Kubal WS (2008) Imaging of orbital trauma. Radiographics 28(6): 1729–1739.

Kumta ND, Park G, Toms A, Housden B & Dixon AK (2002) Body computed tomography in critically ill patients. Anaesthesia 57(6): 544–548.

Lapostolle F, Petrovic T, Lenoir G, Catineau J, Galinski M, Metzger J, Chanzy E & Adnet F (2006) Usefulness of hand-held ultrasound devices in out-of-hospital diagnosis performed by emergency physicians. Am J Emerg Med 24(2): 237–242.

Laurila J, Laurila PA, Saarnio J, Koivukangas V, Syrjala H & Ala-Kokko TI (2006) Organ system dysfunction following open cholecystectomy for acute acalculous cholecystitis in critically ill patients. Acta Anaesthesiol Scand 50(2): 173–179.

Laurila J, Syrjala H, Laurila PA, Saarnio J & Ala-Kokko TI (2004) Acute acalculous cholecystitis in critically ill patients. Acta Anaesthesiol Scand 48(8): 986–991.

Laurila JJ, Ala-Kokko TI, Laurila PA, Saarnio J, Koivukangas V, Syrjala H & Karttunen TJ (2005) Histopathology of acute acalculous cholecystitis in critically ill patients. Histopathology 47(5): 485–492.

Lee KS, Kim TS, Fujimoto K, Moriya H, Watanabe H, Tateishi U, Ashizawa K, Johkoh T, Kim EA & Kwon OJ (2003) Thoracic manifestation of Wegener's granulomatosis: CT findings in 30 patients. Eur Radiol 13(1): 43–51.

Lee MJ, Kim S, Lee SA, Song HT, Huh YM, Kim DH, Han SH & Suh JS (2007) Overcoming artifacts from metallic orthopedic implants at high-field-strength MR imaging and multi-detector CT. Radiographics 27(3): 791–803.

Leidner B, Adiels M, Aspelin P, Gullstrand P & Wallen S (1998) Standardized CT examination of the multitraumatized patient. Eur Radiol 8(9): 1630–1638.

Leppaniemi A, Lamminen A, Tervahartiala P, Haapiainen R & Lehtonen T (1995) Comparison of high-field magnetic resonance imaging with computed tomography in the evaluation of blunt renal trauma. J Trauma 38(3): 420–427.

Licht A, Sibbald WJ & Levin PD (2008) Computerised tomography for the detection of pulmonary emboli in intensive care patients–a retrospective cohort study. Anaesth Intensive Care 36(1): 13–19.

Lichtenstein DA, Lascols N, Meziere G & Gepner A (2004) Ultrasound diagnosis of alveolar consolidation in the critically ill. Intensive Care Med 30(2): 276–281.

Lidegran MK, Ringertz HG, Frenckner BP & Linden VB (2005) Chest and abdominal CT during extracorporeal membrane oxygenation: Clinical benefits in diagnosis and treatment. Acad Radiol 12(3): 276–285.

Livingston DH, Shogan B, John P & Lavery RF (2008) CT diagnosis of Rib fractures and the prediction of acute respiratory failure. J Trauma 64(4): 905–911.

MacMillan M & Stauffer ES (1990) Transient neurologic deficits associated with thoracic and lumbar spine trauma without fracture or dislocation. Spine (Phila Pa 1976) 15(6): 466–469.

Mahid SS, Jafri NS, Brangers BC, Minor KS, Hornung CA & Galandiuk S (2009) Meta-analysis of cholecystectomy in symptomatic patients with positive hepatobiliary iminodiacetic acid scan results without gallstones. Arch Surg 144(2): 180–187.

Major KM, Wilson M, Nishi GK, Farber A, Chopra R, Chung A, McVay C, Spivak J & Shabot MM (2003) The incidence of thromboembolism in the surgical intensive care unit. Am Surg 69(10): 857–861.

Malhotra AK, Fabian TC, Croce MA, Gavin TJ, Kudsk KA, Minard G & Pritchard FE (2000) Blunt hepatic injury: a paradigm shift from operative to nonoperative management in the 1990s. Ann Surg 231(6): 804–813.

Mariat G, Mahul P, Prev tN, De Filippis JP, Cuilleron M, Dubois F & Auboyer C (2000) Contribution of ultrasonography and cholescintigraphy to the diagnosis of acute acalculous cholecystitis in intensive care unit patients. Intensive Care Med 26(11): 1658–1663.

Marmery H, Shanmuganathan K, Alexander MT & Mirvis SE (2007) Optimization of selection for nonoperative management of blunt splenic injury: comparison of MDCT grading systems. AJR Am J Roentgenol 189(6): 1421–1427.

Mathen R, Inaba K, Munera F, Teixeira PG, Rivas L, McKenney M, Lopez P & Ledezma CJ (2007) Prospective evaluation of multislice computed tomography versus plain radiographic cervical spine clearance in trauma patients. J Trauma 62(6): 1427–1431.

Matthes G, Stengel D, Seifert J, Rademacher G, Mutze S & Ekkernkamp A (2003) Blunt liver injuries in polytrauma: results from a cohort study with the regular use of whole-body helical computed tomography. World J Surg 27(10): 1124–1130.

Maunder RJ, Shuman WP, McHugh JW, Marglin SI & Butler J (1986) Preservation of normal lung regions in the adult respiratory distress syndrome. Analysis by computed tomography. JAMA 255(18): 2463–2465.

McCreadie G & Oliver TB (2009) Eight CT lessons that we learned the hard way: an analysis of current patterns of radiological error and discrepancy with particular emphasis on CT. Clin Radiol 64(5): 491–499.

McCullough PA, Adam A, Becker CR, Davidson C, Lameire N, Stacul F, Tumlin J & CIN Consensus Working Panel (2006) Epidemiology and prognostic implications of contrast-induced nephropathy. Am J Cardiol 98(6A): 5K-13K.

McCunn M, Mirvis S, Reynolds N & Cottingham C (2000) Physician utilization of a portable computed tomography scanner in the intensive care unit. Crit Care Med 28(12): 3808–3813.

McGahan JP, Horton S, Gerscovich EO, Gillen M, Richards JR, Cronan MS, Brock JM, Battistella F, Wisner DH & Holmes JF (2006) Appearance of solid organ injury with contrast-enhanced sonography in blunt abdominal trauma: preliminary experience. AJR Am J Roentgenol 187(3): 658–666.

Meeson S, Alvey CM & Golding SJ (2009) Justifying multidetector CT in abdominal sepsis: time for review? Br J Radiol 82(975): 190–197.

Melton SM, Kerby JD, McGiffin D, McGwin G, Smith JK, Oser RF, Cross JM, Windham ST, Moran SG, Hsia J & Rue LW 3rd (2004) The evolution of chest computed tomography for the definitive diagnosis of blunt aortic injury: a single-center experience. J Trauma 56(2): 243–250.

Menaker J, Philp A, Boswell S & Scalea TM (2008) Computed tomography alone for cervical spine clearance in the unreliable patient–are we there yet? J Trauma 64(4): 898–903.

Mets O, Spronk PE, Binnekade J, Stoker J, de Mol BA & Schultz MJ (2007) Elimination of daily routine chest radiographs does not change on-demand radiography practice in post-cardiothoracic surgery patients. J Thorac Cardiovasc Surg 134(1): 139–144.

Miele V, Andreoli C, De Cicco ML, Adami L & David V (2002) Hemoretroperitoneum associated with liver bare area injuries: CT evaluation. Eur Radiol 12(4): 765–769.

Miller PR, Croce MA, Bee TK, Malhotra AK & Fabian TC (2002) Associated injuries in blunt solid organ trauma: implications for missed injury in nonoperative management. J Trauma 53(2): 238–242.

Miller WT Jr, Tino G & Friedburg JS (1998) Thoracic CT in the intensive care unit: assessment of clinical usefulness. Radiology 209(2): 491–498.

Mirvis SE, Tobin KD, Kostrubiak I & Belzberg H (1987) Thoracic CT in detecting occult disease in critically ill patients. AJR Am J Roentgenol 148(4): 685–689.

Mirvis SE, Vainright JR, Nelson AW, Johnston GS, Shorr R, Rodriguez A & Whitley NO (1986) The diagnosis of acute acalculous cholecystitis: a comparison of sonography, scintigraphy, and CT. AJR Am J Roentgenol 147(6): 1171–1175.

Mirvis SE, Whitley NO, Vainwright JR & Gens DR (1989) Blunt hepatic trauma in adults: CT-based classification and correlation with prognosis and treatment. Radiology 171(1): 27–32.

Moore EE, Cogbill TH, Jurkovich GJ, Shackford SR, Malangoni MA & Champion HR (1995) Organ injury scaling: spleen and liver (1994 revision). J Trauma 38(3): 323–324.

Moore EE, Cogbill TH, Malangoni MA, Jurkovich GJ, Champion HR, Gennarelli TA, McAninch JW, Pachter HL, Shackford SR & Trafton PG (1990) Organ injury scaling, II: Pancreas, duodenum, small bowel, colon, and rectum. J Trauma 30(11): 1427–1429.

Moore EE, Shackford SR, Pachter HL, McAninch JW, Browner BD, Champion HR, Flint LM, Gennarelli TA, Malangoni MA & Ramenofsky ML (1989) Organ injury scaling: spleen, liver, and kidney. J Trauma 29(12): 1664–1666.

Morcos SK & Thomsen HS (2001) Adverse reactions to iodinated contrast media. Eur Radiol 11(7): 1267–1275.

Morey AF, Iverson AJ, Swan A, Harmon WJ, Spore SS, Bhayani S & Brandes SB (2001) Bladder rupture after blunt trauma: guidelines for diagnostic imaging. J Trauma 51(4): 683–686.

Mueller C, Buerkle G, Buettner HJ, Petersen J, Perruchoud AP, Eriksson U, Marsch S & Roskamm H (2002) Prevention of contrast media-associated nephropathy: randomized comparison of 2 hydration regimens in 1620 patients undergoing coronary angioplasty. Arch Intern Med 162(3): 329–336.

Nchimi A, Szapiro D, Ghaye B, Willems V, Khamis J, Haquet L, Noukoua C & Dondelinger RF (2005) Helical CT of blunt diaphragmatic rupture. AJR Am J Roentgenol 184(1): 24–30.

Nguyen D, Platon A, Shanmuganathan K, Mirvis SE, Becker CD & Poletti PA (2009) Evaluation of a single-pass continuous whole-body 16-MDCT protocol for patients with polytrauma. AJR Am J Roentgenol 192(1): 3–10.

Papson JP, Russell KL & Taylor DM (2007) Unexpected events during the intrahospital transport of critically ill patients. Acad Emerg Med 14(6): 574–577.

Parizel PM, Ozsarlak, Van Goethem JW, van den Hauwe L, Dillen C, Verlooy J, Cosyns P & De Schepper AM (1998) Imaging findings in diffuse axonal injury after closed head trauma. Eur Radiol 8(6): 960–965.

Parizel PM, Van Goethem JW, Ozsarlak O, Maes M & Phillips CD (2005) New developments in the neuroradiological diagnosis of craniocerebral trauma. Eur Radiol 15(3): 569–581.

Patten RM, Spear RP, Vincent LM, Hesla RB & Jurkovich GJ (1993) Traumatic laceration of the liver limited to the bare area: CT findings in 25 patients. AJR Am J Roentgenol 160(5): 1019–1022.

Pelinka LE, Schmidhammer R, Hamid L, Mauritz W & Redl H (2003) Acute acalculous cholecystitis after trauma: a prospective study. J Trauma 55(2): 323–329.

Phelan HA, Velmahos GC, Jurkovich GJ, Friese RS, Minei JP, Menaker JA, Philp A, Evans HL, Gunn ML, Eastman AL, Rowell SE, Allison CE, Barbosa RL, Norwood SH, Tabbara M, Dente CJ, Carrick MM, Wall MJ, Feeney J, O'Neill PJ, Srinivas G, Brown CV, Reifsnyder AC, Hassan MO, Albert S, Pascual JL, Strong M, Moore FO, Spain DA, Purtill MA, Edwards B, Strauss J, Durham RM, Duchesne JC, Greiffenstein P & Cothren CC (2009) An evaluation of multidetector computed tomography in detecting pancreatic injury: results of a multicenter AAST study. J Trauma 66(3): 641–646.

Philipp MO, Kubin K, Hormann M & Metz VM (2003) Radiological emergency room management with emphasis on multidetector-row CT. Eur J Radiol 48(1): 2–4.

Pinto A, Scaglione M, Guidi G, Farina R, Acampora C & Romano L (2006) Role of multidetector row computed tomography in the assessment of adrenal gland injuries. Eur J Radiol 59(3): 355–358.

Poletti PA, Mirvis SE, Shanmuganathan K, Killeen KL & Coldwell D (2000) CT criteria for management of blunt liver trauma: correlation with angiographic and surgical findings. Radiology 216(2): 418–427.

Porter JM & Singh Y (1998) Value of computed tomography in the evaluation of retroperitoneal organ injury in blunt abdominal trauma. Am J Emerg Med 16(3): 225–227.

Prokop M (2003) General principles of MDCT. Eur J Radiol 45 Suppl 1: S4–10.

Puc MM, Tran HS, Wry PW & Ross SE (2002) Ultrasound is not a useful screening tool for acute acalculous cholecystitis in critically ill trauma patients. Am Surg 68(1): 65–69.

Rana AI, Kenney PJ, Lockhart ME, McGwin G Jr, Morgan DE, Windham ST 3rd & Smith JK (2004) Adrenal gland hematomas in trauma patients. Radiology 230(3): 669–675.

Rees O, Mirvis SE & Shanmuganathan K (2005) Multidetector-row CT of right hemidiaphragmatic rupture caused by blunt trauma: a review of 12 cases. Clin Radiol 60(12): 1280–1289.

Rhee PM, Bridgeman A, Acosta JA, Kennedy S, Wang DS, Sarveswaran J & Rhea JT (2002) Lumbar fractures in adult blunt trauma: axial and single-slice helical abdominal and pelvic computed tomographic scans versus portable plain films. J Trauma 53(4): 663–667.

Rieger M, Czermak B, El Attal R, Sumann G, Jaschke W & Freund M (2009) Initial clinical experience with a 64-MDCT whole-body scanner in an emergency department: better time management and diagnostic quality? J Trauma 66(3): 648–657.

Roddy LH, Unger KM & Miller WC (1981) Thoracic computed tomography in the critically ill patient. Crit Care Med 9(7): 515–518.

Roos JE, Hilfiker P, Platz A, Desbiolles L, Boehm T, Marincek B & Weishaupt D (2004) MDCT in emergency radiology: is a standardized chest or abdominal protocol sufficient for evaluation of thoracic and lumbar spine trauma? AJR Am J Roentgenol 183(4): 959–968.

Rumboldt Z, Huda W & All JW (2009) Review of portable CT with assessment of a dedicated head CT scanner. AJNR Am J Neuroradiol 30(9): 1630–1636.

Salim A, Sangthong B, Martin M, Brown C, Plurad D & Demetriades D (2006) Whole body imaging in blunt multisystem trauma patients without obvious signs of injury: results of a prospective study. Arch Surg 141(5): 468–473.

Salonen EM, Koivikko MP & Koskinen SK (2008) Acute facial trauma in falling accidents: MDCT analysis of 500 patients. Emerg Radiol 15(4): 241–247.

Salottolo K, Settell A, Uribe P, Akin S, Slone DS, O'Neal E, Mains C & Bar-Or D (2009) The impact of the AIS 2005 revision on injury severity scores and clinical outcome measures. Injury 40(9): 999–1003.

Salvolini U (2002) Traumatic injuries: imaging of facial injuries. Eur Radiol 12(6): 1253–1261.

Sammer M, Wang E, Blackmore CC, Burdick TR & Hollingworth W (2007) Indeterminate CT angiography in blunt thoracic trauma: is CT angiography enough? AJR Am J Roentgenol 189(3): 603–608.

Sampson MA, Colquhoun KB & Hennessy NL (2006) Computed tomography whole body imaging in multi-trauma: 7 years experience. Clin Radiol 61(4): 365–369.

Scaglione M, de Lutio di Castelguidone E, Scialpi M, Merola S, Diettrich AI, Lombardo P, Romano L & Grassi R (2004) Blunt trauma to the gastrointestinal tract and mesentery: is there a role for helical CT in the decision-making process? Eur J Radiol 50(1): 67–73.

Scaglione M, Romano S, Pinto A, Sparano A, Scialpi M & Rotondo A (2006) Acute tracheobronchial injuries: Impact of imaging on diagnosis and management implications. Eur J Radiol 59(3): 336–343.

Scalea TM & Mirvis SE (2003) The future of trauma imaging: A clinical perspective. In: Ross A (ed) Imaging in Trauma and Critical Care. Philadelphia, Saunders: 769-771.

Schellinger D, Di Chiro G, Axelbaum SP, Twigg HL & Ledley RS (1975) Early clinical experience with the ACTA scanner. Radiology 114(2): 257–261.

Schurink GW, Bode PJ, van Luijt PA & van Vugt AB (1997) The value of physical examination in the diagnosis of patients with blunt abdominal trauma: a retrospective study. Injury 28(4): 261–265.

Sheedy PF 2nd, Stephens DH, Hattery RR, Muhm JR & Hartman GW (1976) Computed tomography of the body: initial clinical trial with the EMI prototype. AJR Am J Roentgenol 127(1): 23–51.

Sheridan R, Peralta R, Rhea J, Ptak T & Novelline R (2003) Reformatted visceral protocol helical computed tomographic scanning allows conventional radiographs of the thoracic and lumbar spine to be eliminated in the evaluation of blunt trauma patients. J Trauma 55(4): 665–669.

Shreve WS, Knotts FB, Siders RW, Culler A, Fenn-Buderer N & Black C (1999) Retrospective analysis of the adequacy of oral contrast material for computed tomography scans in trauma patients. Am J Surg 178(1): 14–17.

Sliker CW, Shanmuganathan K & Mirvis SE (2008) Diagnosis of blunt cerebrovascular injuries with 16-MDCT: accuracy of whole-body MDCT compared with neck MDCT angiography. AJR Am J Roentgenol 190(3): 790–799.

Smith-Bindman R, Lipson J, Marcus R, Kim KP, Mahesh M, Gould R, Berrington de Gonzalez A & Miglioretti DL (2009) Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Intern Med 169(22): 2078–2086.

Smits M, Dippel DW, de Haan GG, Dekker HM, Vos PE, Kool DR, Nederkoorn PJ, Hofman PA, Twijnstra A, Tanghe HL & Hunink MG (2007) Minor head injury: guidelines for the use of CT–a multicenter validation study. Radiology 245(3): 831–838.

Solomkin JS & Mazuski J (2009) Intra-abdominal sepsis: newer interventional and antimicrobial therapies. Infect Dis Clin North Am 23(3): 593–608.

Soreide K (2009) Epidemiology of major trauma. Br J Surg 96(7): 697–698.

Stacul F, Adam A, Becker CR, Davidson C, Lameire N, McCullough PA, Tumlin J & CIN Consensus Working Panel (2006) Strategies to reduce the risk of contrast-induced nephropathy. Am J Cardiol 98(6A): 59K–77K.

Steigelman M, Lopez P, Dent D, Myers J, Corneille M, Stewart R & Cohn S (2008) Screening cervical spine MRI after normal cervical spine CT scans in patients in whom cervical spine injury cannot be excluded by physical examination. Am J Surg 196(6): 857–862.

Stiell IG, Clement CM, Rowe BH, Schull MJ, Brison R, Cass D, Eisenhauer MA, McKnight RD, Bandiera G, Holroyd B, Lee JS, Dreyer J, Worthington JR, Reardon M, Greenberg G, Lesiuk H, MacPhail I & Wells GA (2005) Comparison of the Canadian CT Head Rule and the New Orleans Criteria in patients with minor head injury. JAMA 294(12): 1511–1518.

Stiell IG, Wells GA, Vandemheen K, Clement C, Lesiuk H, Laupacis A, McKnight RD, Verbeek R, Brison R, Cass D, Eisenhauer ME, Greenberg G & Worthington J (2001) The Canadian CT Head Rule for patients with minor head injury. Lancet 357(9266): 1391–1396.

Suoranta H (2006) Kun TT Suomeen tuli. In: Korhola O, Kivisaari L, Laasonen E, Laasonen L, Paakkala T & Tervonen O (eds) Radiologia Suomessa: Historiikki vuoteen 2005. Helsinki, WSOY: 47–49.

Szem JW, Hydo LJ, Fischer E, Kapur S, Klemperer J & Barie PS (1995) High-risk intrahospital transport of critically ill patients: safety and outcome of the necessary "road trip". Crit Care Med 23(10): 1660–1666.

Taffoni MJ, Ravenel JG & Ackerman SJ (2005) Prospective comparison of indirect CT venography versus venous sonography in ICU patients. AJR Am J Roentgenol 185(2): 457–462.

Tagliabue M, Casella TC, Zincone GE, Fumagalli R & Salvini E (1994) CT and chest radiography in the evaluation of adult respiratory distress syndrome. Acta Radiol 35(3): 230–234.

Teh SH, Sheppard BC, Mullins RJ, Schreiber MA & Mayberry JC (2007) Diagnosis and management of blunt pancreatic ductal injury in the era of high-resolution computed axial tomography. Am J Surg 193(5): 641–643.

Teixeira PG, Inaba K, Hadjizacharia P, Brown C, Salim A, Rhee P, Browder T, Noguchi TT & Demetriades D (2007) Preventable or potentially preventable mortality at a mature trauma center. J Trauma 63(6): 1338–1346.

Tepel M, van der Giet M, Schwarzfeld C, Laufer U, Liermann D & Zidek W (2000) Prevention of radiographic-contrast-agent-induced reductions in renal function by acetylcysteine. N Engl J Med 343(3): 180–184.

The International Collaborative Study of Severe Anaphylaxis (2003) Risk of anaphylaxis in a hospital population in relation to the use of various drugs: an international study. Pharmacoepidemiol Drug Saf 12(3): 195–202.

Tien HC, Tremblay LN, Rizoli SB, Gelberg J, Spencer F, Caldwell C & Brenneman FD (2007) Radiation exposure from diagnostic imaging in severely injured trauma patients. J Trauma 62(1): 151–156.

Tilastokeskus Kuolemansyyt 2007.

Tomiyama N, Muller NL, Johkoh T, Cleverley JR, Ellis SJ, Akira M, Ichikado K, Honda O, Mihara N, Kozuka T, Hamada S & Nakamura H (2001) Acute respiratory distress syndrome and acute interstitial pneumonia: comparison of thin-section CT findings. J Comput Assist Tomogr 25(1): 28–33.

Tomycz ND, Chew BG, Chang YF, Darby JM, Gunn SR, Nicholas DH, Ochoa JB, Peitzman AB, Schwartz E, Pape HC, Spiro RM & Okonkwo DO (2008) MRI is unnecessary to clear the cervical spine in obtunded/comatose trauma patients: the four-year experience of a level I trauma center. J Trauma 64(5): 1258–1263.

Traub M, Stevenson M, McEvoy S, Briggs G, Lo SK, Leibman S & Joseph T (2007) The use of chest computed tomography versus chest X-ray in patients with major blunt trauma. Injury 38(1): 43–47.

Trunkey DD (1983) Trauma. Accidental and intentional injuries account for more years of life lost in the U.S. than cancer and heart disease. Among the prescribed remedies are improved preventive efforts, speedier surgery and further research. Sci Am 249(2): 28–35.

Trupka A, Waydhas C, Hallfeldt KK, Nast-Kolb D, Pfeifer KJ & Schweiberer L (1997) Value of thoracic computed tomography in the first assessment of severely injured patients with blunt chest trauma: results of a prospective study. J Trauma 43(3): 405–411.

Tublin ME, Murphy ME & Tessler FN (1998) Current concepts in contrast media-induced nephropathy. AJR Am J Roentgenol 171(4): 933–939.

Valentino M, Serra C, Zironi G, De Luca C, Pavlica P & Barozzi L (2006) Blunt abdominal trauma: emergency contrast-enhanced sonography for detection of solid organ injuries. AJR Am J Roentgenol 186(5): 1361–1367.

van Breda Vriesman AC, Engelbrecht MR, Smithuis RH & Puylaert JB (2007) Diffuse gallbladder wall thickening: differential diagnosis. AJR Am J Roentgenol 188(2): 495–501.

Van Buul G & Oner FC (2009) Thoracic spinal cord injury without radiographic abnormality in an adult patient. Spine J 9(3): e5–8.

Velmahos GC, Kamel E, Berne TV, Yassa N, Ramicone E, Song Z & Demetriades D (1999) Abdominal computed tomography for the diagnosis of intra-abdominal sepsis in critically injured patients: fishing in murky waters. Arch Surg 134(8): 831–836.

Velmahos GC, Tabbara M, Gross R, Willette P, Hirsch E, Burke P, Emhoff T, Gupta R, Winchell RJ, Patterson LA, Manon-Matos Y, Alam HB, Rosenblatt M, Hurst J, Brotman S, Crookes B, Sartorelli K & Chang Y (2009) Blunt pancreatoduodenal injury: a multicenter study of the Research Consortium of New England Centers for Trauma (ReCONECT). Arch Surg 144(5): 413–419.

Vincent JL, de Mendonca A, Cantraine F, Moreno R, Takala J, Suter PM, Sprung CL, Colardyn F & Blecher S (1998) Use of the SOFA score to assess the incidence of organ dysfunction/failure in intensive care units: results of a multicenter, prospective study. Working group on "sepsis-related problems" of the European Society of Intensive Care Medicine. Crit Care Med 26(11): 1793–1800.

Vincent JL, Moreno R, Takala J, Willatts S, De Mendonca A, Bruining H, Reinhart CK, Suter PM & Thijs LG (1996) The SOFA (Sepsis-related Organ Failure Assessment) score to describe organ dysfunction/failure. On behalf of the Working Group on Sepsis-Related Problems of the European Society of Intensive Care Medicine. Intensive Care Med 22(7): 707–710.

Viscomi S, Shu KM, Blinder EM, MacKenzie JD, Ledbetter S & Rybicki FJ (2004) Quantification of clinical consultations in academic emergency radiology. Acad Radiol 11(11): 1294–1297.

Voggenreiter G, Aufmkolk M, Majetschak M, Assenmacher S, Waydhas C, Obertacke U & Nast-Kolb D (2000) Efficiency of chest computed tomography in critically ill patients with multiple traumas. Crit Care Med 28(4): 1033–1039.

Walcher F, Weinlich M, Conrad G, Schweigkofler U, Breitkreutz R, Kirschning T & Marzi I (2006) Prehospital ultrasound imaging improves management of abdominal trauma. Br J Surg 93(2): 238–242.

Warren J, Fromm RE Jr, Orr RA, Rotello LC, Horst HM & American College of Critical Care Medicine (2004) Guidelines for the inter- and intrahospital transport of critically ill patients. Crit Care Med 32(1): 256–262.

Watts DD, Fakhry SM & EAST Multi-Institutional Hollow Viscus Injury Research Group (2003) Incidence of hollow viscus injury in blunt trauma: an analysis from 275,557 trauma admissions from the East multi-institutional trial. J Trauma 54(2): 289–294.

White CS, Meyer CA, Wu J & Mirvis SE (1999) Portable CT: assessing thoracic disease in the intensive care unit. AJR Am J Roentgenol 173(5): 1351–1356.

Willmann JK, Roos JE, Platz A, Pfammatter T, Hilfiker PR, Marincek B & Weishaupt D (2002) Multidetector CT: detection of active hemorrhage in patients with blunt abdominal trauma. AJR Am J Roentgenol 179(2): 437–444.

Winer-Muram HT, Rubin SA, Ellis JV, Jennings SG, Arheart KL, Wunderink RG, Leeper KV & Meduri GU (1993) Pneumonia and ARDS in patients receiving mechanical ventilation: diagnostic accuracy of chest radiography. Radiology 188(2): 479–485.

Winer-Muram HT, Steiner RM, Gurney JW, Shah R, Jennings SG, Arheart KL, Eltorky MA & Meduri GU (1998) Ventilator-associated pneumonia in patients with adult respiratory distress syndrome: CT evaluation. Radiology 208(1): 193–199.

Winslow JE, Hinshaw JW, Hughes MJ, Williams RC & Bozeman WP (2008) Quantitative assessment of diagnostic radiation doses in adult blunt trauma patients. Ann Emerg Med 52(2): 93–97.

Wintermark M, Mouhsine E, Theumann N, Mordasini P, van Melle G, Leyvraz PF & Schnyder P (2003) Thoracolumbar spine fractures in patients who have sustained severe trauma: depiction with multi-detector row CT. Radiology 227(3): 681–689.

Wintermark M & Schnyder P (2001) The Macklin effect: a frequent etiology for pneumomediastinum in severe blunt chest trauma. Chest 120(2): 543–547.

Wong KT, Antonio GE, Hui DS, Ho C, Chan PN, Ng WH, Shing KK, Wu A, Lee N, Yap F, Joynt GM, Sung JJ & Ahuja AT (2004) Severe acute respiratory syndrome: thin-section computed tomography features, temporal changes, and clinicoradiologic correlation during the convalescent period. J Comput Assist Tomogr 28(6): 790–795.

Wurmb TE, Fruhwald P, Hopfner W, Keil T, Kredel M, Brederlau J, Roewer N & Kuhnigk H (2009) Whole-body multislice computed tomography as the first line diagnostic tool in patients with multiple injuries: the focus on time. J Trauma 66(3): 658–665.

Wurmb TE, Fruhwald P, Hopfner W, Roewer N & Brederlau J (2007) Whole-body multislice computed tomography as the primary and sole diagnostic tool in patients with blunt trauma: searching for its appropriate indication. Am J Emerg Med 25(9): 1057–1062.

Yao DC, Jeffrey RB Jr, Mirvis SE, Weekes A, Federle MP, Kim C, Lane MJ, Prabhakar P, Radin R & Ralls PW (2002) Using contrast-enhanced helical CT to visualize arterial extravasation after blunt abdominal trauma: incidence and organ distribution. AJR Am J Roentgenol 178(1): 17–20.

Zagler A, Azadpour M, Mercado C & Hennekens CH (2006) N-acetylcysteine and contrast-induced nephropathy: a meta-analysis of 13 randomized trials. Am Heart J 151(1): 140–145.

Zhang M, Liu ZH, Yang JX, Gan JX, Xu SW, You XD & Jiang GY (2006) Rapid detection of pneumothorax by ultrasonography in patients with multiple trauma. Crit Care 10(4): R112.

Appendix

Table 19. Indications of Major Blunt Trauma and High-Impact ∆V (Grande & Stene 1991).

Two or more long bone fractures
Unstable pelvis
Flail chest
Sternal, scapular, clavicular, upper rib fractures
Fall from 4.6 m or more (adult), 3.7 m or more (child)
∆V:
30 km/h without restraints
40 km/h with restraints
Rearward displacement of the car by 60 m
Rearward displacement of the front axle
Engine intrusion into the passenger compartment
Frame intrusion into the passenger compartment:
40 cm on the patient's side of the car
50 cm on the opposite side of the car
Ejection of the passenger
Roll-over
Death of another passenger
Pedestrian struck at 30 km/h or more
"Spiderweb" in the windshield
Prolonged extrication

∆V = Change in velocity

Original publications

This thesis is based on the following original articles, which are referred to in the text by their Roman numerals.

I Ahvenjärvi L, Mattila L, Ojala R & Tervonen O (2005) Value of multidetector computed tomography in assessing blunt multitrauma patients. Acta Radiol 46(2): 177–183.

II Ahvenjärvi L, Niinimäki J, Halonen J, Tervonen O & Ojala R (2007) Reliability of the evaluation of multidetector computed tomography images from the scanner's console in high-energy blunt-trauma patients. Acta Radiol 48(1): 64–70.

III Ahvenjärvi LK, Laurila JJ, Jartti A, Ylipalosaari P, Ala-Kokko TI & Syrjälä HP (2008) Multi-detector computed tomography in critically ill patients. Acta Anaesthesiol Scand 52(4): 547–552.

IV Ahvenjärvi L, Koivukangas V, Jartti A, Ohtonen P, Saarnio J, Syrjälä H, Laurila J & Ala-Kokko T (2010) Diagnostic Accuracy of Computed Tomography Imaging of Surgically Treated Acute Acalculous Cholecystitis in Critically Ill Patients. J Trauma, in press.

Reprinted with permission from Informa Healthcare (I, II), Wiley-Blackwell (III) and Wolters Kluwer (IV).

Original publications are not included in the electronic version of the dissertation.

1032. Niinimäki, Maarit (2009) Medical compared with surgical management in induced abortions and miscarriages

1033. Yan, Ying (2009) The antichlamydial effects of drugs used in cardiovascular diseases

1034. Sipola, Annina (2009) Effects of vascular endothelial growth factor (VEGF-A) and endostatin on bone

1035. Kokkonen, Hanna (2009) Aspects of bone sugar biology. Pectin nanocoatings of hard tissue implants

1036. Huhtela, Päivi (2009) Sairaanhoitajien koulutuksen suunnittelu ja toteutus Suomessa vuosina 1945–1957. Terveyssisarkoulut – portti uusille ideoille

1037. Arkkola, Tuula (2009) Diet during pregnancy. Dietary patterns and weight gain rate among Finnish pregnant women

1038. Seppinen, Lotta (2009) The roles of collagen XVIII and its endostatin domain in wound healing, hair follicle cycling and bone development

1039. Länsman, Satu (2009) Evaluation of bioabsorbable poly-L/D-lactide implant for scleral buckling. An experimental study

1040. Bello, Ibrahim O. (2010) Tight junction proteins and cancer-associated fibroblasts in ameloblastoma, ameloblastic carcinoma and mobile tongue cancer

1041. Liimatta, Erkki (2009) Intracellular calcium, preconditioning and regulation of cellular respiration in heart

1042. Korpi, Jarkko (2010) Collagenase-2 (matrix metalloproteinase-8) in tongue squamous cell carcinoma, bone osteosarcoma, and wound repair

1043. Kantomaa, Marko (2010) The role of physical activity on emotional and behavioural problems, self-rated health and educational attainment among adolescents

1044. Volmanen, Petri (2010) Intravenous patient controlled analgesia with remifentanil in early labour

1045. Pääkkönen, Tiina (2010) Melatonin and thyroid hormones in the cold and in darkness. Association with mood and cognition

1046. Nevala, Terhi (2010) Endovascular treatment of an abdominal aortic aneurysm. Mid-term results and management of a type II endoleak

1047. Railo, Antti (2010) Wnt-11 signalling, its role in cardiogenesis and identification of Wnt/β-catenin pathway target genes

Book orders:
Granum: Virtual book store
http://granum.uta.fi/granum/

UNIVERSITY OF OULU P.O.B. 7500 FI-90014 UNIVERSITY OF OULU FINLAND

ACTA UNIVERSITATIS OULUENSIS

SERIES EDITORS

A SCIENTIAE RERUM NATURALIUM

Professor Mikko Siponen

B HUMANIORA

University Lecturer Elise Kärkkäinen

C TECHNICA

Professor Pentti Karjalainen

D MEDICA

Professor Helvi Kyngäs

E SCIENTIAE RERUM SOCIALIUM

Senior Researcher Eila Estola

F SCRIPTA ACADEMICA

Information officer Tiina Pistokoski

G OECONOMICA

University Lecturer Seppo Eriksson

EDITOR IN CHIEF

University Lecturer Seppo Eriksson

PUBLICATIONS EDITOR

Publications Editor Kirsti Nurkkala

ISBN 978-951-42-6148-0 (Paperback)
ISBN 978-951-42-6149-7 (PDF)
ISSN 0355-3221 (Print)
ISSN 1796-2234 (Online)

UNIVERSITY of OULU
OULUN YLIOPISTO