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**EXPLORING NEW PROTOCOLS IN  
EMERGENCY RADIOLOGY, AND THEIR  
IMPACT ON RADIATION AND DIAGNOSIS**

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To  
My family and my beloved daughter  
Delvin



## **ABSTRACT**

Computed tomography (CT) has become the predominant radiological examination in thoracic and abdominal emergencies. The increasing use of CT, both for diagnosis and follow-up and the continued development of the CT technique demand that we improve our examination protocols constantly. The aim of this thesis has been to explore new examination protocols and to study their effect on diagnosis and on radiation dose to the patient.

Papers I and II evaluate protocol modifications of abdominal CT. In Paper I, focused abdominal and pelvic CT were assessed to find out if the examination could be limited (i.e. focused) to the area of interest based on the patients symptoms. In patients with symptoms and signs suggestive of upper abdominal disease, the results indicate that CT can be limited to this area. In patients with symptom from the lower abdomen this may, however, not be true because of the phenomenon of referred pain and CT of the whole abdomen could therefore be indicated.

In Paper II, the use of enteral contrast agent was evaluated in patients with suspected appendicitis. Enteral contrast agents administered rectally, orally or both did not differ from the diagnostic results of the protocol with CT performed without enteral contrast. Thus there is no need for delay and/or breaking the patient's fast before surgery by administration of enteral contrast.

In Papers III and IV, low dose (sometimes referred to ultra low dose) thoracic CT (LDCT) was studied. In Paper III LDCT was compared with normal dose chest CT in patients admitted to the intensive care unit and in Paper IV, LDCT was compared to bedside chest X-ray in emergency patients. Both studies demonstrated high accuracy and reliability of LDCT for diagnosis of chest disease in the emergency setting.

## LIST OF PUBLICATIONS

- I. **Latifi A**, Torkzad O, Labruto F Ullberg U, Torkzad MR.  
The accuracy of focused abdominal CT in patients presenting to the emergency department. *Emerg Radiol.* 2009May; 16 (3): 209-15.
  
- II. **Latifi A**, Labruto F, Kaiser S, Ullberg U, Sundin A, Torkzad MR.  
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- III. Börjesson J, **Latifi A**, Firman O, Beckman MO, Oldner A, Labruto F.  
Accuracy of low-dose chest CT in intensive care patients.  
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- IV. **Latifi A**, Beckman MO, Sundin A, Torkzad MR, Labruto F.  
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## 1 LIST OF ABBREVIATIONS

ABC	Airways-breathing-circulation
AP	Antero-posterior
ARDS	Adult respiratory distress syndrome
bCXR	Bedside chest X-ray
CAT	Computerized axial tomography
CCU	Coronary care unit
CHF	Congestive heart failure
CIN	Contrast induced nephropathy
CT	Computed tomography
CXR	Chest X-ray
DLP	Digital Light Processing
DNA	Deoxyribonucleic acid
ECG	Electrocardiogram
FFA	Focus Film Distance
GE	General Electrics
ICC	Intraclass coefficient
ICU	Intensive care unit
IV	Intravenous
IVC	Intravenous contrast
kV	KiloVolts
LDCT	Low-dose computerized tomography
M/F	Male/Female
mA	MilliAmpere
MDCT	Multidetector computed tomography
mgI	Milligram Iodine
mL	Milliliter
mm	Millimeter
MRI	Magnetic resonance imaging
mSv	MilliSievert
NICU	Neurosurgery-oriented intensive care units
PA	Postero-anterior
PACS	Picture archiving and communication system
Sv	Sievert



## 2 INTRODUCTION

The number of radiological examinations is increasing with the major rise being due to computed tomography examinations (CT). This seems to be the trend all over the world with radiology becoming the dominant form of diagnosis. This is due to several factors; one of them is the high accuracy of CT. CT is increasingly used in acute abdominal examinations as it provides a higher diagnostic accuracy than clinical examination and laboratory tests [1].

CT outperforms other modalities in regard to covering a large area of body in an expeditious way while still providing the means for a correct diagnosis. Ultrasonography (US) is best used for focused examinations. Although whole-body protocols for magnetic resonance imaging (MRI) have been developed, this technique similarly is best suited for examinations of limited body regions. Also, for lung disease, CT is more advantageous than MRI because of the better spatial resolution and US, which cannot be used at all for diseases of the lungs.

CT is also relatively cheap compared to magnetic resonance imaging (MRI) and hospital admission. This makes CT an invaluable method of triage. In the words of one lecturer, "as long as CT is cheaper than average-priced funeral" we will see it being used in increasing numbers. Finally CT is less reader-dependent than both MRI and ultrasound.

CT however entails several side effects. The most widely known is ionizing radiation [2]. In fact, this is probably the most common cause of mortality among patients that are examined by radiologists. It is estimated that one patient of every 2,000-3,000 will develop malignancy, and one of every 1000-1500 patients will perish as a result [3]. While CT causes less radiation than many interventional radiological procedures, CT is replacing interventional procedures when it involves diagnosis only. CT is the one of the most important source of ionizing radiation to the population. Plain film examinations are much less cumbersome in this aspect.

The second main problem with CT occurs when intravenous contrast agents are used in patients that are prone to the development of contrast-induced-nephropathy or CIN.

Finally, increased workload can lead to delays for CT and its interpretation. Furthermore, surgical patients who have had enteral contrast agents may need to fast before surgery. This phenomenon may be responsible for more complications seen in patients who have undergone CT compared to those undergoing surgery directly [4].



### **3 BACKGROUND**

In the following, brief descriptions of the most important clinical entities that are pertinent to this thesis are covered. This is followed by a general background about ionizing radiation.

#### **3.1 ACUTE ABDOMEN**

Acute abdomen is a generic term for several acute abdominal diseases with intense pain as the dominant manifestation. Gastroenteritis in its usual form therefore is not considered acute abdomen since diarrhea and nausea are more prominent features.

Dealing with acute abdominal pain is one of the surgeon's most important and also most difficult tasks. Experience has shown that a careful clinical examination, especially repeated palpation of the abdomen, is essential, but reaching an accurate diagnosis is often difficult and not feasible only on clinical grounds. For example in the case of ruptured aortic aneurysm, the diagnosis should be made promptly and without undue delay. Nevertheless, clinical examination prior to CT examination is essential and mandatory. In the first work we have tried to look at relation between clinical findings and the pathology focus. Our aim has been to see that if clinical examination and the information conveyed to the radiologist can be used for tailoring the field of abdominal and pelvic CT, or to focus CT on the upper abdomen vs. lower abdomen and pelvis. Nowadays, it is customary to examine the whole abdomen and pelvis in such cases, at least in Sweden.

The most common identifiable cause of surgical acute abdomen is appendicitis [5]. Other common causes of acute abdomen are biliary diseases including gallstones, ileus, urinary tract diseases, including ureteral stone colic, diverticulitis, pancreatitis and gynecological disorders. In the second work, appendicitis has been the focus of the study. Appendicitis is assumed to be caused by obstruction of the opening of appendix (or somewhere along the appendix lumen) leading to inflammation. Untreated, most authors agree that acute appendicitis will progress to complications. Studies have shown that negative appendectomy, i.e. appendectomy for suspicion of appendicitis when appendicitis is not present, leads often to increased morbidity. One can understand that accurate diagnosis and avoidance of unnecessary surgery is an important goal. However, several surgeons have voiced their concerns for widespread application of CT [6]. They have observed increased number of complications seen in patients undergoing CT. The reason for this is not clear however it seems to be true [7]. In other words, it does not seem to be the result of selection of more severe cases undergoing CT. One may speculate that delay in diagnosis with CT can be contributing. Aside from common delays for CT, many hospitals advocate enteral contrast agents for CT for appendicitis. Contrast enema, oral contrast agent, or both are sometimes used [8]. The reason for using enteral agents seems to stem from the era when non-visualization of appendix on colon enema was considered a sign of appendicitis. Furthermore, CAT, which was available first, had several limitations compared to recent CT in delineating bowel loops [9].

Oral contrast agents are usually preferred by radiologists and radiology staff compared to contrast enemas. Due to nausea and delayed transit caused by local paralysis close to the site of inflammation, most authors and radiologists wait two to three hours after ingestion of oral contrast agents. Furthermore, after CT is performed, the fast of the patient is broken or at least the patient needs to fast anew. This delay in addition to the delay before CT can easily explain at least some of the increased number of perforations seen in connection with CT.

The goal of the second study was therefore to examine whether enteral contrast agents are necessary for accurate diagnosis of appendicitis in the era of MDCT.

### **3.2 DISEASES OF THE CHEST**

Thoracic diseases are a usual major cause of concern. Pulmonary and cardiac diseases can be life threatening. In fact diseases of these organs are encompassed by the ABC principle of resuscitation. "A" stands for airway, while "B" and "C" stand for breathing and circulation, respectively. The number of diseases of these organs seems countless. From a radiologic standpoint some of these diseases are of more concern to us than the others. Diseases that compromise the airways, or lead to decreased air exchange space should be easily diagnosed with radiologic means.

Air causes extremely low attenuation of X-ray and has therefore very low CT density. This contributes to excellent contrast to other tissues. Conditions that lead to opacification of the airspaces are therefore relatively easy to detect. These conditions could be increased amounts of fluid in the pleura (pleural effusion), or atelectasis and pulmonary consolidations. These conditions are frequently seen in patients with shortness of breath or dyspnea and their prompt diagnosis is important.

Despite the excellent contrast between air and densities caused by fluids or tissue, these diagnoses can sometimes be missed or at least difficult to establish on chest X-ray (CXR). Consolidations can be small or of lower density and be missed on two-dimensional CXR images. Consolidations can lie behind the heart or close to vasculature/mediastinal structures and be missed. Both pleural effusions and consolidations can be situated in a pleural sinus and be missed altogether. It is therefore sometimes mandatory to have thoracic CT to rule out these possibilities or help confirm them.

Cardiac diseases and disease of the major vessels are more difficult to diagnose with X-ray means as heart and central vessels partially overlap as well lie over mediastinum and vertebral column on CXR. Radiologists should try to provide simple estimates of heart size and diagnosis of congestive heart failure (CHF) relies to a great extent on whether or not the heart is enlarged. For this reason postero-anterior (PA) views of the chest are desirable as the heart is closest to the X-ray detector. Obtaining PA views is however more difficult in the emergency settings where patients are less ambulatory. It is therefore much more common to obtain antero-posterior views (AP). Unfortunately, all the above stated limitations of CXR are more enhanced in the AP projection.

Another problem with cardiovascular diagnoses on CXR is aortic aneurysm and dissection and pericardial effusions (excessive fluid in the sac surrounding the heart). Even though for some conditions such as pulmonary embolism and aortic dissection the use of vascular contrast agents are obligatory on CT, CT without contrast can undoubtedly provide more information than CXR or at least help with increased diagnostic confidence especially in less experienced readers.

The superiority of CT in all these diagnoses however comes at the price of increased radiation burden to the patient. This is particularly true when these examinations need to be repeated frequently. When CT is performed after an inconclusive CXR or a CXR which does not adequately help to explain the patient's condition, the radiation dose of the initial CXR, albeit small, needs to be added to total radiation burden.

Furthermore CT is not commonly available at the patient bedside. This is not always an issue as many radiology departments require patients to be transferred to radiology for "bedside" X-rays. Nonetheless, mobile, bedside X-ray is invaluable for many patients such as those in the intensive and cardiac care units (ICU and CCU, respectively).

Considering these issues, it seems prudent to come to a compromise that could mean lowering the radiation dose in chest CT. It should not surprise us to know that low dose chest CT (LDCT) would prove to be more accurate than CXR. The questions however before making any similar changes in policy is to know to what extent patients benefit from such paradigm shifts. The third and fourth studies are therefore aimed to provide an estimate in a smaller scale.

### **3.3 RADIATION**

Radiation is a term often fraught with fear. Every now and then some form of radiation is blamed for a new or an old problem. While one must always study every claim from a scientific point of view, it is radiation with sufficient energy that might cause damage to tissues [10].

Radiology as a medical specialty employs imaging to both diagnose and treat disease visualized within the human body. Radiologists use different imaging modalities (e.g. X-ray, US, CT, nuclear medicine, positron emission tomography (PET) and MRI) to diagnose or treat diseases. Interventional radiology is the performance of (minimally invasive) medical procedures with the guidance of imaging technologies. The acquisition of medical imaging is usually carried out by the radiographer or radiologic technologist. The radiologist then interprets the findings and makes a report of these findings and provides a diagnosis.

In radiology we distinguish ionizing radiation from other forms of radiation as the form of radiation that can cause damage. Ionizing radiation is the portion of the electromagnetic spectrum with sufficient energy to pass through matter and physically push out electrons from their orbits to form ions. These ions, in turn, can produce tissue changes. Examples of ionizing radiation are radiation from space and from the natural radioactive substances. Medical diagnostic procedures are currently the greatest manmade source of ionizing radiation exposure to the general population. However, even these sources are generally quite limited

compared to the general background radiation on earth. It is the potential DNA damage that might increase cancer risk. It is however very common that radiation is used and considered synonymous to ionizing radiation. X-ray is the form of ionizing radiation that concerns us in this thesis.

Different units are used to describe and measure radiation energy such as decay activity rate (curie [Ci] or becquerel [Bq]), effect in air (röntgen [R]), ability to be absorbed (radiation-absorbed dose [rad] or gray [Gy]), or biologic effects (röntgen equivalent man [rem] or Sievert [Sv]). The current preferred measurement for absorbed dose per mass is gray (Gy). However, different tissues can have different absorbed doses and, therefore, different biologic effects. The Sievert (Sv) is the unit for equivalent dose in the System International (SI) system. It shows the amount of radiation received by each organ and relative sensitivity. Sievert (Sv) is a unit named after the Swedish physicist Rolf Sievert. 1 Sv is a very large dose, and therefore the unit milliSievert (mSv) is commonly used in medicine.

Whenever using ionizing radiation in medicine one should ensure that all exposures are justified and optimized. This irradiation is justified when the benefit to the patient, i.e. correct diagnosis or treatment, is considerably greater than the (potential) harm caused. High dose of irradiation can cause cell death and DNA repair damage. The former can lead to loss of function and in the latter case increased risk of malignancy.

The typical radiation doses in Sweden are 0.05-6 mSv for conventional radiology, 2-10 mSv for CT and 12 mSv for interventions<sup>1</sup>. An interesting site for patients to understand the risks with radiologic tests is <http://www.xrayrisk.com/index.php>. According to this site the increased risk for development of cancer in a 30 year old male is 1/815 for standard CT of abdomen-pelvis, 1/1426 for abdominal CT (equivalent to upper abdomen in Paper I), 1/1902 for pelvic CT (equivalent to lower abdominal CT in Paper I), 1/1630 for standard chest CT, 1/19339 for LDCT, and 1/16300 for 2 view CXR.

### 3.4 COMPUTED TOMOGRAPHY

A CT scanner comprises a short tunnel (gantry) and an examination couch. The gantry holds the X-ray tube and on the opposite side of the tunnel several rows of X-ray detectors. While the X-ray tube and the detectors rotate, the patient lies on the couch and is slowly moved through the gantry. For a large number of angles during each rotation, the attenuation (absorption) of the X-rays in the body is registered. This is accomplished by during each rotation calculating the difference between the X-rays from the tube and those that reached the detectors. A powerful computer process the attenuation data and 2D CT images are displayed in gray-scale on a computer screen. These can be reformatted to coronal image volumes to visualize the body from

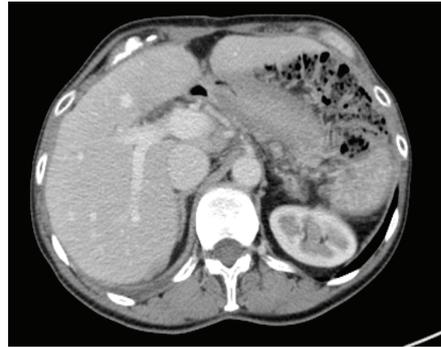
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<sup>1</sup>

<http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Myndighetshandling/Granskningsrapport/Rapporter/%20till%20webben/samlad-stralsakerhetsvardering-av-halso-och-sjukvarden-2005-2010.pdf>

front to back or as sagittal image volumes displayed from left to right (Figure 1). MDCT (Figure 2) employs a varying number of detectors sensitive to X-rays. These detectors are mechanically coupled to the X-ray tube and can be rotated around the patient.

**Figure 1:** A cross sectional CT image of the upper abdomen. The right side of the body is depicted to the left side of the image and the front (or ventral) part is depicted to the top of the image. In this image the liver occupies most of the space to the right side of the patient, while on the left; the left kidney is shown posterior (dorsally) with the gastrointestinal tract located anteriorly.



As mentioned previously, the number of indications for which CT can be used is limitless. CT comprises 15% of radiological examinations today and is responsible for 70% of total radiation burden. CT is used for screening for diseases (e.g. colon and lung cancers), detection of many disease processes (such as finding conditions and tumors that cause excessive hormone production), providing differential diagnoses (e.g. finding the reason for acute abdomen), defining the extent and distribution of disease (e.g. tumor staging), assessment of treatments (e.g. tumor response), providing prognostic indicators (such as blood flow of a tumor), providing models for surgery and interventions, forensic medicine and archeological researches.

CAT was the first line of medical CT machines. As machines have evolved, we have seen spiral CT followed by MDCT (Figure 2). Today, it is very difficult to be up-to-date on the latest machines when it comes to the number of detectors. Other forms of CT such as cone beam and dual energy source CT are less commonly used but nonetheless important.

**Figure 2.** Image of a typical MDCT at our department. The patient is placed on the bed, usually in the supine position and then the bed and the patient move thru the hole, i.e. gantry.

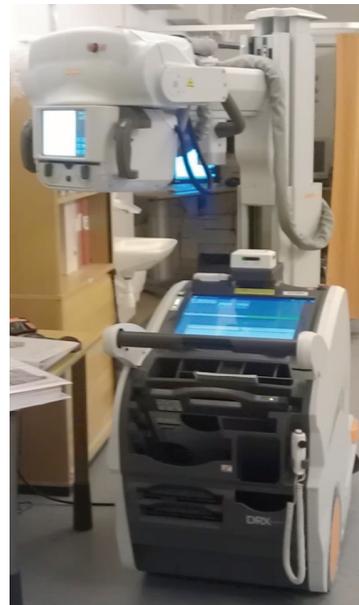


### 3.5 CHEST X-RAY (CXR)

Another form of X-ray used is simple bedside X-ray (Figure 3 and 4). In the following we will focus on CXR, which will appear in our studies. Other bedside radiologic examinations are bedside CT, employed at some neurosurgery-oriented intensive care units (NICU), and ultrasound.

Bedside CXR always involves positioning a film cassette under the patient chest and the tube directed vertically in an AP fashion. This is called a frontal or AP view. The bedside frontal view is different from the usually standing PA view obtained for ambulatory patients. . The standing patient is by contrast examined with the chest towards the cassette and with the X-ray tube behind the patient. The size of the anteriorly positioned heart is more accurate to estimate on the PA views than AP views. Other structures and organs also follow the same rule. However heart size is the most important size measurement on a CXR.

**Figure 3.** A typical mobile X-ray unit used for bedside imaging.



**Figure 4.** The actual “bedside” apparatus used in Paper IV. With these machines the patient is brought to radiology unit; however the images are classified as bedside because the patient position remains the same, supine.



The fact that the AP views are normally obtained on bed-ridden supine patients also contributes to the differences observed between bedside supine AP and upright PA views. Collapse of the dependant portions of the lung (atelectasis) and redistribution of pulmonary blood flow to better aerated areas are common problems and issues with imaging supine patients, who have less ability to cooperate with instructions and inhale deeply. Dangling tubes, catheters, i.v. lines, ECG pads, bed sheet wrinkles, slightly rotated patients or angled views are almost the rule rather than the exceptions and impose severe limitations to the quality of the images in connection with bedside CXR of the supine patient (Figure 5).

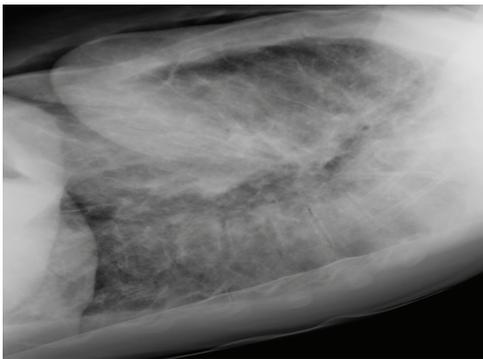
**Figure 5.** Two different frontal views of the chest on two different occasions. The left image is an AP supine image of a patient at bedside, while the right image is obtained while the patient is

standing.



While frontal views are almost always obtained for bedside CXR, other views and projections are less common. At Karolinska University Hospital Solna, lateral views of the chest are routine procedure (Figure 6). Interestingly, other radiology units at Karolinska do not adhere to this protocol.

**Figure 6.** Bedside lateral view of a supine patient.



## **4 AIMS**

To examine the accuracy of focused abdomino-pelvic computed tomography (CT) in patients presenting to the acute department

To evaluate the accuracy of multidetector CT of abdomen and pelvis for diagnosis of appendicitis in relation to the route of enteral agent used.

To compare the accuracy of low dose chest computed tomography (LDCT) to standard dose chest CT in adult intensive care unit patients

To compare the diagnostic yield of bedside chest X-ray and LDCT



## 5 METHODS AND MATERIALS

### 5.1 GENERAL ASPECTS

#### 5.1.1 Study populations

All studies involved adult patients referred to the Radiology Department Solna at the Karolinska University Hospital Solna. In Papers I and II we looked into abdominal and pelvic diseases studied by CT as the only method. Both these studies were done in a retrospective fashion on patients who had undergone these studies previously. The cases were consecutive cases as the ethical committees approved such an inclusion. There was no intention for any patient participating in more than one study, however this was not checked nor constituted an exclusion criterion.

In Paper III and IV we looked at dose CT of the chest in two separate prospective groups of patients. Informed consent was asked for primarily, due to additional imaging of the patients and the prospective nature of the study. All patients gave informed consent. Pregnant patients were excluded.

Randomization of the populations was not applied in any of the studies involved. As previous knowledge within these areas was scanty, there was no power analysis for determination of sample sizes. This is particularly pertinent to the last two papers which involved prospective studies and therefore the studies are more of a pilot nature.

#### 5.1.2 Radiologic studies

##### 5.1.2.1 CT

###### 5.1.2.1.1 Abdomino-pelvic CT

In the first two studies the abdomino-pelvic CT were performed on 16 slice MDCT (Lightspeed VCT, General Electric Medical System, Milwaukee, WI, USA). The helical slice thickness was 0.625 mm, pitch 1.375, reconstruction soft body, 120 kV with automatic mA (smart mA). The images were reconstructed in axial, coronal and sagittal projections with 5 mm thickness and 2.5 mm index when sent and stored in PACS (Picture archive and communication system).

###### 5.1.2.2 *Thoracic CT*

###### 5.1.2.2.1 Full dose:

For Paper III a 64-row MDCT was used (Lightspeed VCT, General Electric Medical System, Milwaukee, WI, USA). The collimation was 64 x 1.25, kV 120 with automatic mA. The images sent to PACS were reconstructed with both soft tissue and lung algorithms. The reconstructed

planes were the standard planes of axial, coronal and sagittal.

#### 5.1.2.2.2 Low dose MDCT

For Papers III and IV the same MDCT was used. The only variables changed were kV which had been reduced to 100 and exposure was fixed at 70 mAs.

#### 5.1.2.3 *bCXR*

In Paper IV, MDCT and bCXR used. For bCXR AP view and a lateral view of the lungs utilized a Discovery XR650 system (General Electric Medical Systems, Milwaukee, WI, USA). The parameters used for bCXR were, for the AP view: 150kV, 2.5 mAs, 1.3 m FFA (Focus Film Distance) and landscape. The corresponding parameters for the lateral view were 140 kV, 6.8 mAs, 1.3 m and portrait.

## **5.2 DETAILS PARTICULAR TO EACH STUDY POPULATION:**

### **5.2.1 Paper I**

This study comprised 189 patients, born between 1955 and 1990 and examined at our center with abdomino-pelvic CT in 2005. This adult group was selected because sensitivity to radiation is the highest among younger adults. Only patients who had been examined for the first time at our department were chosen. We chose patients who were studied for the first time as we assumed previous images might have and should play a role in choosing the focus of any future radiologic study.

The images of the patients in this study were divided into upper and lower parts (focused). This distinction was made on the iliac crest on scout images and roughly corresponds to division into abdomen and pelvis. This division was made by the main author, radiographer.

Another author, radiologist, based on these divisions, noted whether the pathology on CT was located in the upper, lower or both parts of the abdomen-pelvis.

Another author, clinician, divided the requests based on the available information into where the pathology would be suspected, upper, lower or both parts. This distinction was based on predefined criteria (see Table 1).

**Table 1. Criteria for classification of patients based on clinical information available in the radiological (CT) request forms in Paper I.**

Part of the abdomen-pelvis examined	Criteria	Comments and explanation to reason for adoption of different focus policies
B. Whole abdomen should be examined (suspicion or verified)	Kidney stones or their complications	The whole urinary tract needs to be examined
	Ileus, bowel obstruction etc	The whole GI tract needs to be examined
	Inflammatory bowel disease	
	Abdominal pain in whole abdomen	
	Central abdominal pain	
	Unclear and diffuse abdominal discomfort	Too vague symptoms or too little information for focusing CT
	Patient unable to provide clinical information (e.g. substance abuse, alcohol intake, coma, etc)	
known malignancies	The whole abdomen-pelvis should be examined in search of metastases.	
U. Only the upper part of the abdomen needs to be examined	None of the above (B criteria) plus one of the following	Assumption that in these patients FCT of the upper abdomen would be adequate
	Signs of pancreatitis	
	Suspicion of cholecystitis.	
	Clear signs of liver affection such as jaundice (slight rise in liver enzyme levels was not considered adequate)	
	Pain only in the upper abdomen	
L. Only the lower part of the abdomen can be examined	None of the above (B criteria) plus pain only in the lower abdomen	Assumption that in these patients FCT of the lower abdomen would be adequate

### **5.2.2 Paper II**

For this study, cases of abdomino-pelvic CT performed 2005-2006 for the first time at our center were chosen. These cases had to be done with our 16 channel MDCT and a specific suspicion of appendicitis had to be asked in the referral. In other words the referring physicians had specifically asked the radiologist to rule out appendicitis.

In this study the route of enteral contrast agents were recorded by the main author. These routes were either oral, rectal, both oral and rectal and finally no enteral agent. The choice of enteral contrast had been made by the on-call radiologist(s). The agents however are administered according to department routines. For oral route 30 mL Gastrografin 370 mgI/ml is added to 1 liter tap water given 90-120 minutes before the examination. For enema, 50 mL Gastrografin 370 mgI/ml is added to warm water 30 minutes before CT.

The finalized reports were divided into two groups based on diagnosis of appendicitis, positive for presence of appendicitis versus negative.

The reference test was surgery and histopathology in cases leading to surgery or follow-up otherwise.

### **5.2.3 Paper III**

15 patients were enrolled in this study (11/4 M/F). They were selected from ICU patients referred for chest CT. Both standard as well as low doses CT were evaluated independently by a pair of radiologists. In cases of disagreement a third radiologist resolved the disagreement by consensus. The radiologists were asked to evaluate the presence of consolidation, pleural or pericardial effusions, and pneumomediastinum or pneumothorax. The overall image quality and confidence in evaluation of position of catheters and tubes was also recorded. The radiation dose was calculated based on reported dose-length product multiplied by normalized effective dose of 0.017 for chest examinations.

### **5.2.4 Paper IV**

This study was a prospective, non-randomized study. Sixteen patients (11 males, 5 females) were enrolled into the study. Their median age was 76 (range 65 – 97). All patients were examined without intravenous contrast-enhancement on a 64-row MDCT within 30 minutes after bCXR. Cohens' kappa and intraclass correlation coefficient (ICC) were used to estimate agreement between measurements made on either modality by the three radiologists. The images were viewed separately by three experienced radiologists who were blinded to the patient history and all clinical data. The questionnaire was the same for bCXR and LDCT images and the radiologists were asked to evaluate the presence, measurement and subjective grading (e.g. small, moderate and large amount) of pulmonary atelectasis, pleural effusion, alveolar and interstitial infiltrate, pneumothorax, heart size and position of tubes and i.v. lines (Table 2).

The radiation dose for each CT examination was calculated by multiplying the dose-length product (DLP) reported for each examination and the normalized effective dose for the chest (0.017). The radiation dose for routine bCXR was previously calculated to 0.5 mSv for AP and 0.2 mSv for lateral view adding up to 0.7 m Sv.

**Table 2. List of studied variables on both bedside chest X-ray and non-enhanced low dose chest CT in Paper IV**

- Pneumothorax present or absent for each lung
  - Atelectasis (defined as pulmonary consolidation with volume loss with or without bronchogram) for each lung
    1. None or minimal
    2. Present with a volume less than one lobe
    3. Present with a volume larger than one lobe
  - The depth of atelectasis in an antero-posterior diameter wherever largest in mm for each lung
  - Pleural effusion in each hemithorax
    1. None or minimal
    2. Present with a volume that probably does not demand treatment
    3. Present with a volume that probably requires treatment
  - Depth of pleural effusion in an antero-posterior diameter in the deepest point of effusion in mm for each thorax
  - Alveolar infiltrates (defined as alveolar filling processes, i.e. opacification of the airspaces without volume loss) present or absent for each lung
  - Interstitial thickening of pulmonary septae present or absent for each lung
  - Heart size
    - Maximum antero-posterior diameter in cm
    - Maximum left-right diameter in cm
  - Catheters. For each catheter/tube the following had to be answered:
    - What is the catheter?
    - Where is the tip situated?
    - Are there any problems with its course?
  - Other important findings
  - Confidence in radiologically important diagnosis (excluding pulmonary embolism)
    1. Cannot assess. The possibility of missing a radiological diagnosis is high. Another radiologic examination should be added.
    2. Possibly correct. The possibility of missing a radiological important diagnosis is considerable and another radiological examination should be considered.
    3. Probably correct. The likelihood of missing a diagnosis is not high. Another radiological test may be considered.
    4. Confident diagnosis. The likelihood of missing a radiological important diagnosis is low and no other test is necessary.
-



## 6 RESULTS

### 6.1 PAPER I

6,281 cases had been examined with CT performed at our institution during the study period. 189 (3%) fulfilled the inclusion criteria. The mean and median age of these patients was 35, ranging from 15 to 50 years.

The diagnoses, when available or not, are summarized in Tables 3 and 4.

62% of patients did not have any pathological findings on CT. 36 of these had lower abdominal signs and symptoms (L), 17 had upper abdominal symptoms (U) and finally 64 the symptoms were not limited to one area (B).

In total 100 patients had problems with symptoms that were not limited to upper or lower abdomen-pelvis. In the remaining 89 of the original 189 (47%) the referral gave clues that the examination could potentially be focused, 29 from the upper abdomen and 60 lower abdomen and pelvis. The 29 cases had either no pathology shown on CT (17) or pathology only in the upper abdomen.

In the 60 cases with symptoms from the lower abdomen and pelvis, 36 had no pathology seen on CT, 19 had pathology in the lower abdomen and pelvis, 2 had pathology in the upper abdomen and finally 3 had pathology in both parts. The latter three included one case of appendiceal abscesses and the other two had urologic problems. Two patients with symptoms from the lower abdomen and pelvis showed no findings in the lower part of CT but highly located appendiceal inflammations in the upper abdomen (Figure 7).

**Table 3. Verified pathologies demonstrated on CT in Paper I**

Diagnosis	No. of cases	Location of pathology	Comments
Duodenal ulcer	2	Upper FCT	Confirmed with endoscopy
Cholecystitis	3	Upper FCT	Confirmed by surgery/histopathology
Appendicitis or tumor of the appendix	24	1 upper FCT 2 both lower and upper FCT, 21 lower FCT,	Confirmed by surgery or follow-up for 15-31 months. One patient had carcinoid without metastases.
Pelvic inflammatory disease (PID)	3	2 Lower FCT, 1 No CT findings	Confirmed by gynecological examination
Diverticulitis	8	Lower FCT	No cancer was shown on colonoscopy and follow-up
Trauma	15	7 contusions in upper FCT (2 spleen, 1 liver, 3 kidney, 1 rib). Others without any pathologies	None of the patients demonstrated any pathology in lower FCT, except one patient with spleen rupture who had small amounts of fluid in the lower FCT not essential for diagnosis. Confirmation was with surgery and/or follow-up.
Pancreatitis	4	Lower FCT	Confirmed by history, laboratory tests and follow-up.
Abscess without any other pathologies	1	Lower FCT	Confirmed by puncture and follow-up.
Postoperative abscess	5	4 lower, 1 upper FCT	Confirmed by puncture and follow-up.
Abscess secondary to PID	1	Both lower and upper FCT	Confirmed by puncture and follow-up.
Ileus due to Crohn's disease	2	Both lower and upper FCT	Known Crohn's disease. Confirmed by puncture and follow-up.
Peritoneal carcinomatosis	1	Both lower and upper FCT	Previously unknown tumor. Confirmed by puncture and follow-up.

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Kindeg stones hydronephrosis	+/-	5	Both lower and upper FCT	All demonstrated distal stones and hydronephrosis. Confirmed by history, puncture, cystoscopy, urography and follow-up.
Pyelonephritis		2	Both lower and upper FCT	Confirmed by laboratory tests and follow-up.
Lokal recurrence of tumor	of	1	Lower FCT	Confirmed by puncture and follow-up.
Stangulated bowel hernia	wall	1	Both lower and upper FCT	Missed on CT.
Bleeding in kidney cyst		1	Upper FCT	Final clinical diagnosis. No abnormalities during follow-up.
Perforated bladder	urinary	1	Lower FCT	Extravasation of instilled contrast agent.
Ovarial torsion		1	Lower FCT	Surgery

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**Table 4: Other diagnoses or findings that could not be confirmed by radiological, surgical or histopathological findings in Paper I**

No. of cases	Comments
1	Patient with Crohn's disease. The clinical assessment was relapse of Crohn's disease. CT did not reveal any findings that could corroborate such diagnosis (no previous CT available).
4	Mesenteric lymphadenitis. Spontaneous improvement.
1	Pain likely due to badly placed intrauterine device.
2	Suspicion of ovarian torsion.
8	Simple urinary tract infection (cystitis) with or without laboratory tests.
2	Dermal infections.
1	Leukemia.
9	Gastroenteritis.
1	Ruptured follicular cyst.
1	Lumbago.
1	Irritable Bowel Syndrome
1	Psychiatric problems.

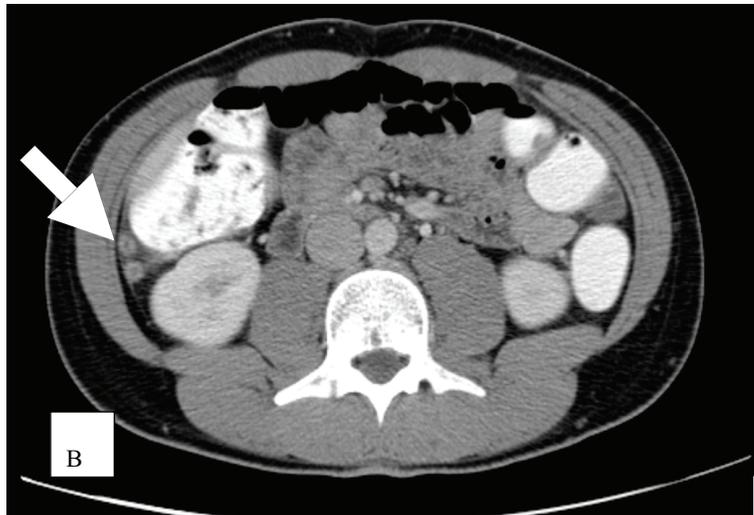
**Table 5. Correlation between suspected location of pathological findings as suggested by the information provided in the request form and the location of pathology as shown on CT in Paper I. For definition of B, U, and L, please see Table 1.**

		Location of pathology based on request form		
		B	U	L
Location of pathology on CT	No pathologic findings on CT	64	17	36
	Upper FCT	11	12	2*
	Lower FCT	17	0	19
	Both upper and lower FCT	8	0	3†

\*: Patients with appendicitis who had CT findings only on upper FCT.

†: 1 patient with appendicitis who had multiple abscesses, 1 patient had pyelonephritis, 1 patient with ureteral stone where hydronephrosis contributed to the diagnosis.

**Figure 7.** The scout image (a) depicts where in the abdomen the image is from. As clearly seen this is an image of upper FCT (above the iliac crest). The slightly inflamed appendix (arrow) can be seen to the right behind the tip of the liver (image b). This patient had symptoms only from the lower abdomen (L criteria) and pathologic findings only on upper CT.



## 6.2 PAPER II

69 patients out of 246 included cases (28%) had a diagnosis of appendicitis (Table 6). 23% of patient who had received no enteral agents (115 cases) had appendicitis, 30% of patient who had received enema (74 cases), 42% of those without any enteral agent (21 cases) and 31% of those with both enema and oral agents had appendicitis. There was no statistical significant difference between these groups regarding incidence of appendicitis. Almost all cases had been correctly diagnosed with the exception of two false positive and two false negative cases. The false positive cases were seen in the group with oral only and enema only. The false negative cases were seen in the oral only and those without any enteral agents. There was no statistical significant difference between measured sensitivities (89-100%), specificities (98-100%), positive (96-100%) and negative predictive (92-100%) values.

**Table 6. Sensitivity, specificity, accuracy, positive and negative predictive values (PPV and NPV, respectively) for diagnosis of appendicitis, based on type of enteral contrast used as studied in Paper II-**

Method	If oral and rectal together are considered separate groups				If oral and rectal together are NOT considered separate groups			Total
	Oral	Rectal	No enteral	Both oral and enteral	Oral	Rectal	No enteral	
Number of cases	115	74	36	21	136	95	36	246
True positive	26	22	11	8	34	30	11	67
False positive	1	1	0	0	1	1	0	2
True negative	88	51	25	12	100	63	25	176
False negative	0	0	0	1	1	1	0	1
Sensitivity (%)	100	100	100	89	97	97	100	99
Specificity (%)	99	98	100	100	99	98	100	99
PPV (%)	96	96	100	100	97	97	100	97
NPV (%)	100	100	100	92	99	98	100	99
Accuracy (%)	99	99	100	95	99	98	100	99

### 6.3 PAPER III

The average DLP in the standard-dose CT examination was 395 mGy/mm, which accounts for an estimated average radiation dose of 6.7 mSv. The average DLP in the LDCT examination was 34 mGy, which accounts for an estimated average radiation dose of 0.59 mSv. Thus, the average radiation dose in the LDCT scans was 11 times smaller than in standard-dose CT.

With LDCT, consolidation was observed in 27 true-positive cases of 30 cases, demonstrating a sensitivity of 90%. Since none of the lungs examined were free from consolidation, specificity for this finding could not be calculated.

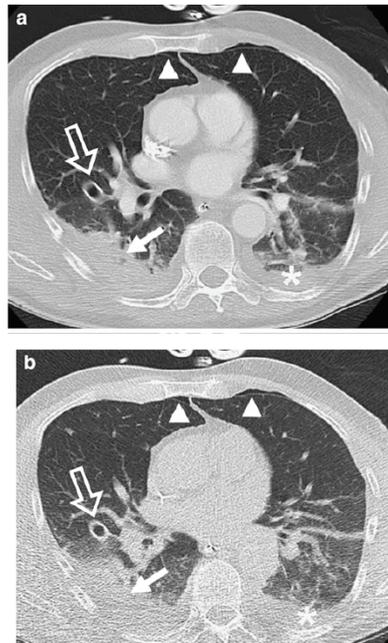
With LDCT, pneumothorax was observed in four true positive cases of total 7 cases, demonstrating 57.1% sensitivity. There were no false positive cases, i.e. 100% specificity (Figure 7).

With LDCT, pleural effusion was observed in 19 true positive cases of total 20, demonstrating 95% sensitivity. No cases of false positive pleural effusion were reported, demonstrating 90% specificity.

With LDCT, pericardial effusion and pneumomediastinum were observed in the only one true-positive case each demonstrating 100% sensitivity and specificity 100%.

On a scale of 1 to 3, with 1 representing an examination of insufficient quality and 3 of sufficient quality, the two radiologists who read the LDCT examinations rated them, on average, 2.4. In all cases, both readers judged the resolution of the images adequate for assessing the position of chest tubes, venous and arterial lines, and endotracheal tubes and cannulas.

**Figure 8.** CT image of the chest in the same patient examined with standard dose (a) and low dose (b) protocols. The small bilateral pneumothoraces (arrowheads), the lung contusion (arrow), the pleural effusion (asterisk) and the chest tube (empty arrow) can be visualized on both images.



#### 6.4 PAPER IV

Sixteen patients (M/F 11/5) were enrolled. Their median age was 76 (range 65 – 97). In the following whenever conditions of pleurae and/or lungs are discussed (e.g. pneumothorax or pulmonary opacities) “cases” refers to each pleura or lung, respectively. On a 1 to 4 scale (table 2), the average confidence score was 2.85 for bCXR reading and 3.83 for LDCT reading.(table 7) The confidence score for LDCT was never below 3 and the radiologists never recommended further imaging after LDCT. In contrast, low confidence scores of 1-2 were reported for 13 bCXR readings in 7 patients (44% of patients), warranting further imaging (Table 3). All radiologists at LDCT correctly diagnosed the only case of pneumothorax among the 16 patients (Cohen’s kappa = 1). On bCXR, however, two radiologists missed the pneumothorax while two radiologists made a false positive diagnosis of pneumothorax in two different patients (Cohen’s kappa = 0.94).

Cohen’s kappa was 0.83 for measurement of agreement on degree of atelectasis on bCXR and 0.79 for LDCT, denoting perfect and strong agreements, respectively. Objective measurements of atelectasis extent were much more consistent on LDCT than on bCXR. ICC was 0.36 for bCXR and 0.64 for LDCT, fair and moderate agreements, respectively.

On both LDCT and bCXR, the maximum score difference was 1 on LDCT readings for pleural effusion; by contrast, four cases showed 2 point score difference on bCXR assessment. Cohen’s kappa was 0.66 for bCXR and 0.71 for LDCT, both corresponding to strong agreement.

There were 8 discordant cases for bCXR and 12 for LDCT on whether alveolar opacities were present or not. The Cohen’s kappa was 0.89 for bCXR and 0.71 for LDCT, perfect and strong agreements, respectively. Interestingly, 4 lungs were read as having opacities on LDCT by all three radiologists while none of them noted this finding on bCXR in any of these lungs. These four lungs were from three different patients.

ICC was 0.43 for heart dimension measured on bCXR and 0.82 on LDCT, reflecting moderate and perfect agreements, respectively. The antero-posterior diameters measured on bCXR were on average 2.5 cm larger than those measured on LDCT cm while this difference was on average 2.3 cm on left-right dimension measurements. These dimensions were recorded higher on almost all hearts size measurements at bCXR compared to LDCT. The Bland-Altman plot shows a systemic bias with overestimation of the heart size at bCXR compared to LDCT. The 95% confidence interval of heart size measurements showed higher size measurements on bCXR, 0.04 to 3.96 cm difference, which is statistically significant.

In two patients, pulmonary malignancy was detected by two radiologists on LDCT but was missed by all three viewers on bCXR. Two patients had free intra-abdominal air, which was not detected at bCXR. One nasogastric tube was considered to be located too high by all three radiologists on LDCT but was overlooked by all three viewers at bCXR. There were no diagnoses detected at bCXR that were missed at LDCT.

**Table 7. Results of comparison of some variables between non-enhanced low dose chest CT (LDCT) and bedside chest X-ray (CXR)**

**ICC: Intraclass correlation coefficient**

Finding	CXR	LDCT	Comments
Confidence score (1-4)	2.85	3.83	LDCT always $\geq$ CXR
Confidence score 1-2 by any radiologist (% of patients)	44%	0%	
Pneumothorax	<ul style="list-style-type: none"> <li>• 1 false negative by two radiologists</li> <li>• 2 false positive cases by one radiologist each</li> </ul>	0	Reference test: LDCT
Agreement on depth of atelectasis (ICC)	0.36	0.64	
Agreement on depth of pleural effusion (ICC)	0.27	0.74	
Heart size dimension measurements (ICC)	0.43	0.82	

## 7 DISCUSSION

The four above mentioned studies set out to analyze different possible CT protocol improvements in the setting of acute cases. Two of these studies explored changes in the abdomino-pelvic protocols and both were retrospective studies with a considerable number of patients. The latter two studies examined protocol with very low radiation dose for chest CT and compared it first to standard CT and in another study with bCXR. These studies were conducted prospectively and with far fewer numbers of patients due to the explorative nature of these so-called pilot studies. While three of the studies looked more specifically at radiation dose, the second study even explores alteration in patient preparation.

All studies have their strong and weak points, but nonetheless only make a tiny scratch on the surface of innumerable number of possible explorative studies. Our focus has been CT studies of thorax and abdomen-pelvis, however, ultrasound, MRI and other methods as well as other body parts can be examined as well. What we have done here however is neither the start nor the finish of the endless endeavor to improve our diagnostic capabilities without or with less harm to the patient. This is part of an ever-continuing struggle of humans to preserve and cherish life.

### 7.1 PAPER I

This study demonstrates that there is a good correlation between the location of the pathology as suggested by clinical information in the request form for CT and where pathology is shown later on CT.

This was most obvious in patients with symptoms from the upper abdomen only (U criteria). If only focused CT had been performed within this group, no mistakes could have been done and no important diagnoses missed. The reason for this is probably due to lack of symptoms in the lower abdomen and pelvis from diseases in the upper abdomen. For example gallbladder problems are known for causing shoulder pain [11], commonly known as referred pain [12]. On the other hand we do not know of any pain referred from upper to lower abdomen.

Another explanation could be that we used better and clearer signs to define criteria U, for instance jaundice and elevation of serum amylase levels.

We can probably conclude that in patients with symptoms similar to those with criteria U, the CT can be focused to upper part of the abdomen-pelvis without loss of essential information. In this way we can reduce radiation dose to radiation-sensitive organs such as the ovaries [13]. Another conclusion could be of course advocated increased use of ultrasound of the upper abdomen when symptoms suggest such an approach. Unfortunately, this was the smallest group in our study (29/189 patients i.e. 15%), which mandates larger studies to confirm our results.

The largest group in our study (53%) was the one with symptoms consistent with criteria B which we believed necessitate imaging of the whole abdomen-pelvis. In case of

prospective studies, it might have been possible to have more patients with criteria U or L. Only 8% of patient with criteria B had pathology on both upper FCT and lower FCT. This is however the reality we face, with requests sometimes not encompassing all data. Even with prospective studies, “difficult” cases can be excluded initially and making generalizations difficult. Most patients with pathologies had them only on lower FCT. Better initial clinical assessments may also improve better patient triage into selection of upper or lower abdomen-pelvis focused CT.

Even patients with criteria L had most pathologies only on lower FCT with or without simultaneous pathologies seen on upper FCT. An important subgroup within those with criteria L was patients with diverticulitis. Diverticulitis can be seen in all parts of the colon [14, 15]. The most common location, however, for diverticulitis is the sigmoid colon and the descending colon. There is always the possibility of cancer being present simultaneously with diverticulitis or simulating diverticulitis [16]. Because of this colonoscopy is used in all our patients initially thought to have diverticulitis even with CT being done. It could be argued that presence of liver metastases on CT would affect accuracy of diagnosis [17]. Colonoscopy however is always advocated at our center, with possibility of upper FCT reserved for patients who do demonstrate cancer on colonoscopy. Additionally, in the younger adult age group chosen by us, the prevalence of colon cancer is much lower, especially below age 40 [18].

Patients with appendicitis are however more difficult to evaluate. Appendicitis is one of the most common afflictions of the younger patients [19]. Different strategies have been used for dose reduction among patients with suspected appendicitis. One has been pelvic CT [20]. There are important differences between the latter study and ours. Kaiser, et al, only examined children with suspected appendicitis. We examined adults with all abdominal emergencies. In addition they imaged the pelvis without contrast enhancement which could greatly influence interpretation of the results. Finally, they imaged the pelvis regardless of symptoms, only based on suspicion of appendicitis. Nevertheless, it appears that appendicitis is a difficult diagnosis based only on lower FCT. In order to approve this limitation of CT attempts have been made to localize cecum [21, 22]. In the first study, there is no comparison between focused and unfocused CT. The authors had still a sensitivity of 93% and specificity of 97%. In the latter study there was no contrast agent given on focused CT and comparison was made with CT with both oral and intravenous contrast agents.

We did not have any patients with disease of the aorta, which could be due to our patients age [23]. The number of negative cases in patients with criteria B, L or U did not differ ranging from 59% to 64%.

An important group of patients are those with feared post-operative complications. In these patients the complications were usually at or close to the site of surgery, either in the upper or lower FCT. This probably means that imaging of the whole abdomen is not necessary with suspicion of post-operative abscess.

Other than what is mentioned above our study suffered from several limitations. One limitation is the low number of cases. The figure 189 is relatively high compared to some studies, yet we looked at different conditions and diseases, and per disease the number of cases is low.

We have intentionally included several diagnoses, believing that this is both an advantage as well as disadvantage of our study. Some authors for instance regard cecal diverticulitis as false positive diagnosis in patients with suspected appendicitis [24]. While it is true that the treatment is different, still cecal diverticulitis is in the same position as appendicitis. To focus on diagnosis without consideration for the imaged area was not our primary objective.

We also employed a complicated system for our gold standard. For instance we had three patients who had benign liver lesions too difficult to adequately assess on CT, yet follow-up and other imaging methods such as MRI and ultrasound with contrast-enhancement demonstrated the benign nature of these findings, which did not demand treatment. We did not include such accidental findings which did not require treatment. Nevertheless, the patients in our study were young adults and the likelihood of finding incidental malignant tumors was not high.

The radiation dose measured at our center with the 64 multislice CT used was 2.2 mSv effective dose. Of this 1.35 mSv was on average given to lower FCT area, while 0.85 was given to upper FCT. If only upper FCT had been used in patients with criteria U, 61% of the radiation could have been reduced.

## **7.2 PAPER II**

The results of this study indicate that when the appendicitis is suspected, regardless of which type of enteral contrast is used or not (oral contrast agents, contrast enema, both or none), the accuracy of the abdominal MDCT performed with 64 MDCT remains high. This, we believe, is a reflection of the robust nature of CT for making a diagnosing of appendicitis. Previously non-visualization of appendix was considered as a sign of appendicitis, today we rely mainly on direct visualization of the appendix [25-29].

We had delivered a questionnaire to the radiologists and residents working at our institution and at the University Hospital of Uppsala, where the co-author Michael Torzkad is currently working (results now shown). Interestingly it seemed that the less experienced radiologists were mostly positive to administration of some form of enteral contrast agents for diagnosis of abdominal emergencies, while the more experienced radiologists were mostly negative to use of contrast agents. The main approach to administration of enteral agents is by oral route. Administration of oral contrast agents has traditionally been used for visualization of the small bowel, assuming that structures not containing high density are not bowel loops [30]. Administration of high-density agents has been challenged for better delineation of mucosal enhancement in small bowel diseases [31, 32]. The role of oral agents is shifting from simple demarcation of contrast agent-containing loops to simple distention of the loops. There are three other problems with oral agents.

Firstly, it takes one to three hours for the contrast agent column to reach the cecum in healthy adults, with researchers striving to reduce that time to about 50 minutes or lower [33]. This could mean unnecessary delay in diagnosis if patients with appendicitis could be diagnosed

earlier. Another problem is that appendicitis and other local inflammatory process sometimes cause local paralysis, commonly referred to sentinel loop sign on plain film [34, 35]. The paralysis causes a further delay in contrast agents reaching in sufficient amounts to the involved area. Finally, there is always the problem of nausea in patients with appendicitis [36, 37], making administration of oral agents difficult.

Administration of contrast enema has the advantage of giving control to the radiologist in filling the bowel, and less delay than the oral approach. This approach is however more invasive even if slightly to the patients. Furthermore, the filling of colon must be monitored somehow in patients. Without monitoring, there could be no guarantee that the contrast agent column has reached cecum and appendix. Monitoring contrast agent means some form of radiological fluoroscopy which means increased radiation to the patient. This however could perhaps be offset by using focused CT around the area of cecum [38, 39].

Though contrast enema is in some ways more attractive than the oral approach, our study suggests that the accuracy is high even without any enteral agents. Perhaps one of the most difficult groups for imaging is the pediatric age group with less abdominal fat separating the bowel loops. In a series of studies by Kaiser, et al, and other studies, CT with only intravenous contrast agents has proven itself highly accurate [40-42]. In the studies by Kaiser, however, there are fewer differential diagnoses to abdominal pain in children compared to adults. Another aspect is the impact of high density contrast agents on radiation dose. Today CT machines can make an initial assessment of dose needed based on scout views. Presence of high contrast density agents can affect this and lead to rise in radiation dosage. We however observed no significant difference regarding radiation dose difference in our subjects based on type of enteral agents used.

There are certain limitations in our study. Firstly the retrospective nature of the study in comparison to a prospective study makes our study potentially weaker. A plausible consequence of the retrospective nature of our study was that we did not define the criteria for diagnosis of appendicitis on CT and the criteria for suspecting appendicitis on clinical grounds.

The only study that compares abdominal CT with and without oral contrast is the study by Lee and colleagues [43]. The major problem with this study as well as other prospective studies is how to isolate the effect of i.v. contrast agents. It is understandable that the same patient cannot be imaged twice using both methods without some technical as well as ethical issues. One can however, randomize patients into different groups. While an attractive study design, it is highly unlikely that the results of a prospective study would fare differently compared to our study.

One issue that was not touched by our study is other diagnoses in patients without appendicitis. Contrast agents could be administered not because of question of appendicitis but because of other possible alternatives. While this might be the case, our study indicates that the choice of enteral contrast agents does not need to be changed for the sake of appendicitis.

We even looked at radiologists with different degrees of experience, though the results were not shown. We did not find any noticeable differences in accuracies, and we believe therefore that

there is no support for the claim that enteral agents might be helpful when radiologist's experience is less.

### **7.3 PAPER III**

Strategies for radiation dose reduction in CT of the chest have been extensively studied in the elective patient. In this study, we prospectively tested the accuracy of LDCT of the chest in the critically ill, adult intensive care patients.

The main finding of our study is that a tenfold reduction of the radiation dose yielded 100% accuracy in the diagnosis of pneumomediastinum, pericardial effusion, and pleural effusion, as well as 90% accuracy in the diagnosis of pneumothorax and consolidation.

However, considering the small size of the group, calculating the accuracy in percentages could exaggerate mistakes made in diagnoses. We therefore retrospectively analyzed the material in an attempt to critically review the misdiagnosed conditions and were able to observe the following: There were three cases of false-negative consolidations. However, in these three cases, the consolidations were very small, and because of their typical, dependent appearance, they were interpreted as atelectasis and did not lead to any intervention whatsoever. This diagnostic mistake may be due to the fact that LDCT scan was carried out without contrast enhancement. Intravenous contrast agent improves the accuracy in the differential diagnosis of atelectasis vs. pulmonary infiltration or other diseases [44].

There were three cases of false-negative pneumothorax. However, in all three cases, the pneumothorax was smaller than 10 mL and was always found in the presence of a chest tube, which implies that the false-negative finding could not have clinical consequences. Interestingly, all involved radiologists were able to retrospectively identify the pneumothoraces on the LDCT scans.

Finally, there was one case of false-negative pleural effusion. However, the effusion was very small and did not warrant drainage or other intervention. We observed two cases of false-positive pleural effusion. Again, this may be due to the absence of intravenous contrast agent, which makes it difficult to distinguish pleural effusion from pulmonary consolidation. Intravenous contrast agent improves the accuracy in the differential diagnosis of atelectasis vs. pleural effusion [45]. Given the design of the study, it is not possible to judge what consequences the two false-positive findings of pleural effusion may have led to. However, it is very unlikely that these two false-positive diagnoses could lead to anything of consequence: drainage of pleural effusion is normally performed under ultrasound guidance, and this method would have rectified the false-positive diagnosis. No false-positive findings were observed for any other endpoints.

Both the blinded participants in the study judged the quality of the LDCT examination satisfactory. In particular, the participants felt confident in their ability to judge the position of tubes and lines, which is a recurrent clinical question in intensive care medicine.

Intensive care patients are usually exposed to relatively high doses of ionizing radiation [46]; this is particularly true for trauma patients and those in need of repeated examinations [47]. We speculated that the chest diagnoses that are most common in intensive care could be made even when images have reduced resolution and increased noise.

Obviously, specific clinical questions may warrant the use of standard dose protocols, notably the diagnosis of pulmonary embolism. Recent studies have addressed the question of dose reduction in chest CT for the diagnosis of pulmonary embolism [48, 49]. This, however, was outside the purposes of our study.

A limitation of this study is that many chest conditions (such as emphysema and lung abscess) were not included in the evaluation protocol. We are, therefore, not able to determine the accuracy of LDCT for detection of such potentially important pathologies.

Among the conditions that were not evaluated was adult respiratory distress syndrome (ARDS). The CT diagnosis of ARDS is mainly based on the distribution of pulmonary infiltration [50]; our protocol performed fairly well on recognition of pulmonary infiltration; however, none of the examined patients had ARDS; therefore, we were not able to assess the accuracy for this specific clinical question.

Another limitation was the restricted size of the selected group. The reason for selecting only 15 patients was due to the fact that, as a result of the local ethical committee's policies, patients could be included in the study only if a next of kin could sign the informed consent beforehand, which hampered the recruitment process.

#### **7.4 PAPER IV**

This study in a limited number of patients demonstrates the benefits from using LDCT compared to bCXR without increasing the radiation dose to the patient. The involved radiologists were constantly more confident when assessing LDCT than when reading bCXR and objective measurements similarly showed higher degrees of agreement with LDCT.

Though confidence is subjective, the present results are not surprising. We always expect the diagnostic yield by CT, and even LDCT, to be better than with bCXR. A previous observational study of adult patients presenting to 12 emergency departments found poor sensitivity (43.5%) for CXR among 3423 patients with acute cardiopulmonary symptoms when using CT of the thorax as the reference [51]. Moreover, 27% of pneumonias, diagnosed by CT, were overlooked at CXR in another study [52]. In yet another study, there were additional findings at CT of the thorax with impact on treatment, in 16% of patients even in those in whom CXR had suggested pneumonia [53].

The findings we looked at in this study are perhaps the most important ones that could be assessed on non-enhanced chest CT and did not include trauma victims. One study focused on traumatic findings, such as lung contusion, hemothorax, and pneumothorax, showed large discrepancies in diagnostic yield between bCXR and CT of the thorax [54].

It is noteworthy that bCXR in our institution also is comprised of a lateral view, which theoretically should improve our assessment of pneumothorax and pleural effusion which often are located ventrally and dorsally, respectively. Consequently, with only an AP view, smaller pneumothoraces and pleural effusions can even more easily be missed.

Our study also suggests a better agreement among radiologists for objective measurements on LDCT compared to bCXR. It is well known that CXR, even upright, is associated with high inter-observer discrepancies for different diagnoses [55]. However, with the use of qualitative assessment this advantage for LDCT was not apparent, and even slightly better agreement was demonstrated for bCXR in this respect. This is an interesting observation, the reasons for which we cannot fully explain. Though better agreement signifies robustness of the examination protocol it does not take accuracy into account. This probably explains why better agreement for alveolar opacities and interstitial thickening was found for bCXR because these findings were systematically missed by all viewers at bCXR as opposed to LDCT. Another plausible explanation is the subjective nature of these assessments. Consequently, while LDCT provides better insight for example into how much pleural effusion is present this does not necessarily mean that the radiologists evaluating the same volume reach the same conclusion. The real gain of LDCT may therefore be lost if a qualitative rather than quantitative assessment is used.

We also demonstrated the well-known problem of heart dimension measurements on bCXR. The overestimation of heart size at bCXR is explained by the fact that in the AP projection, the anterior chest structures are magnified because they are positioned farther from the detector compared to the PA projection of CXR obtained in the upright position.

According to our examination protocol, the radiation dose for LDCT was very low, actually similar to what is now called an ultra low-dose chest CT [56]. We have previously shown that LDCT can compete with normal CT [Paper III] for the diagnosis of common chest conditions in the intensive care settings, which has also been shown for the demonstration of metastatic pulmonary nodules [57].

This study has several limitations. The study group was small and we included only patients 65 years and older. In this age group the risk of radiation-induced cancer is less and one may use normal radiation dose CT more freely. However, we did not want to introduce more radiation, albeit low, in younger patients at this initial phase of study, hence the age selection.

At our institution, we also obtain a lateral bCXR view for the bedside examination, which, at least in our country, is more an exception than the rule. Without a lateral view we would have lowered the radiation dose to the patient but probably also decreased the diagnostic yield of the examination.

bCXR is a well established examination that will probably remain the mainstay for diagnosis of many chest conditions in the nearest future. However, with the general ongoing transition from plain film studies to CT, for a variety of traditional indications, and the increasing availability of CT scanners in the intensive care units, CT examinations of the thorax are also likely to increase.



## **8 THESIS SUMMARY**

### **8.1 PAPER I**

It is probable that in patients with symptoms and signs of disease in the upper abdomen and below the age of 50 the pelvis does not need to be imaged. This however needs to be validated by larger prospective studies.

In patients with symptoms and signs from the pelvis however, there might be loss of significant findings if the upper abdomen is not imaged and/or better criteria have not developed.

### **8.2 PAPER II**

There is no need for any type of enteral contrast agents for MDCT diagnosis of appendicitis.

### **8.3 PAPER III**

In selected patients a tenfold reduction in radiation dose can be achieved by use of chest LDCT in comparison to standard chest CT without significant loss of diagnostic information.

### **8.4 PAPER IV**

Chest LDCT should be considered an invaluable alternative to bCXR for diagnosis and follow-up of patients.



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I



## The accuracy of focused abdominal CT in patients presenting to the emergency department

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**Abstract** Focused computed tomography(CT) examination (FCT) is CT limited to a specific abdominal area in an attempt to reduce radiation exposure. We wanted to evaluate FCT on the basis of information from the request form and thus reduce radiation dose to the patient without missing relevant findings. We retrospectively analyzed 189 consecutive acute abdominal CT, dividing the findings as localized in the upper or lower abdomen. Another researcher blindly determined where the CT should be focused to, based only on information provided in the request form. The sensitivity and specificity of FCT in patients with

symptoms from only upper abdomen was 100%. Sensitivity, specificity, and accuracy of FCT in patients with symptom from only lower abdomen were 79%, 100%, and 92%, respectively. Our study suggests that among patients with symptoms from the lower abdomen, not examining the upper abdomen would lead to missing relevant findings.

**Keywords** Computed tomography (CT) · Radiation dose · Diagnosis · Physical examination · Abdominal pain

A large number of acute abdominal–pelvic computed tomography (APCT) is performed in patients with symptoms from the abdomen, and the number seems to be increasing. A look at the local statistics at our department reveals that this figure has been rising by 10–20% for each year since 2002. This is probably due to the high accuracy of CT [1–3]. Another factor responsible for increased usage of CT has been the strained resources and costs of admitting patients for observation [4].

CT usage however entails an increased radiation dose to patients [5]. This is most important in the younger patients [6]. The radiation dose of APCT at our center has been documented and is 2.2 mSv on average. There have been several attempts to reduce radiation dose to patients through changes in CT protocol such as adjusted radiation dose [7]. For instance, unenhanced CT of the urinary tract has been employed with less radiation dose since calcifications are seen well even with reduced radiation [8].

Another way of reducing the radiation dose could be the limitation of the radiation field (focused CT or FCT). Very few studies have been conducted in this field [9–12]. The primary objective of this retrospective study was to examine the accuracy of FCT in patients with acute abdominal symptoms.

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## Materials and methods

We collected a series of consecutive cases of adult patients (born between 1955 and 1990) examined at our center with APCT during 2005 for the first time in their lives. This age group was chosen because of higher sensitivity to radiation, yet consisting of adults who could provide adequate patient history. The data were extracted from the local Radiology Information System (RIS). Only patients referred from the emergency department were included. Patients whose request form did not contain any information or referred for simultaneous examination of other body parts (e.g., thorax) were excluded.

Ethical aspects: the local ethical committee approved the study. In accordance with a quality control study, no patient information or consent was sought in this retrospective study.

### Upper and lower focused CT

One of the researchers (AL) divided the images stored on the local picture archiving and communications system (PACS) into upper and lower parts based on the upper border of the iliac crest on the scout images. In this way, two series imaging of upper FCT and lower FCT were created.

### Gold standard

An experienced radiologist (MRT) blinded to the clinical history evaluated first all images and noted the location of the pathologic findings as belonging to the field of upper FCT, lower FCT, or both. The results of the above described analysis were also compared to the original examination report, which is customarily signed by two radiologists.

Later, all clinical data between the date of the CT examination and March 2007 (including journal entries, radiological studies, gastroscopy and/or colonoscopy histopathological findings, and surgical reports), were reviewed for validation of radiological findings. The reason for such extensive follow-up was mostly to avoid inclusion of unimportant findings as essential findings. The following diagnoses were therefore excluded after review of all clinical data: benign adrenal adenomas (incidentalomas), benign lesions in solid organs that did not require therapy (e.g., benign liver or kidney cysts or hemangiomas), and small amounts of free fluid in the abdomen in women without any other pathologic findings or consequences which could explain the fluid.

The following diagnostic tools were used specifically for the following diagnoses:

- Histopathology for diverticulitis, appendicitis, and other findings that demanded biopsies or surgeries. The

rationale for this was that it was believed that in most of these cases such as diverticulitis where colon cancer could not be reliably ruled out, the inclusion of the upper abdomen would be necessary in CT examination for ruling out metastases.

- Radiological follow-up, for instance, for patients with suspected urinary colic urography could be employed.
- Colonoscopy for ruling out malignancies in patients with diverticulitis.
- Clinical follow-up for verification of psychosomatic disorders, irritable bowel syndrome, or gastroenteritis.
- Laboratory tests to verify urinary tract infection, and pancreatitis.

### Tested variable

Another researcher (OT) with access to only the information provided in the request form divided the patients in groups based on the following criteria to find the possible location of the suspected pathologies as outlined in Table 1.

### Statistical methods

Sensitivity, specificity, and accuracy were calculated after tabulating the results in Excel files.

## Results

Cases, 6,281, had been examined with CT at our center during 2005. Of these, 189 (3%) fulfilled our inclusion criteria. The mean and median age of these patients was 35, ranging from 15 to 50 years. Patients, 116 (61%), received oral contrast agents, 173 (92%) patients IV contrast agents, 40 (21%) patients rectal contrast agents, and one patient had contrast agent instilled in his urinary bladder.

The final results of definitive pathologies are shown in Table 2. Table 3 shows cases where diagnoses were made largely on clinical examination and without histopathological or radiological confirmation.

### Correlation between location as suggested by request form and gold standard

The results are summarized in Table 4. Of patients, 62% did not have any pathological findings on CT. Among those with pathologic findings, there was a good correlation between location of the pathology as suggested by the request form and location of pathology on CT. Most patients had pathologies demonstrated in the lower abdomen with or without concomitant findings in the upper abdomen. Among patients with symptoms from only the

**Table 1** Criteria for classification of patients based on clinical information available in the radiological (CT) request forms

Part of the abdomen–pelvis examined	Criteria	Comments
B. Whole abdomen should be examined (suspicion or verified)	Kidney stones or their complications	The whole urinary tract needs to be examined
	Ileus, bowel obstruction etc	The whole GI tract needs to be examined
	Inflammatory bowel disease	The whole GI tract needs to be examined
	Diffuse and generalized abdominal pain	The whole abdomen–pelvis needs to be examined
	Central abdominal pain	The whole abdomen–pelvis needs to be examined
	Unclear and diffuse abdominal discomfort	Too vague symptoms for focusing CT
U. Only the upper part of the abdomen needs to be examined	Patient unable to provide clinical information (e.g., substance abuse, alcohol intake, coma, etc)	Too little or less reliable information for adequate to focus CT
	Known malignancies	The whole abdomen–pelvis should be examined in search of metastases
	None of the above (B criteria) plus at least one of the following	Assumption that in these patients FCT of the upper abdomen would be adequate
	Signs of pancreatitis	
	Suspicion of cholecystitis.	
	Clear signs of liver affection such as jaundice (slight raise in liver enzyme levels was not considered adequate)	
L. Only the lower part of the abdomen can be examined	4. Pain only in the upper abdomen	
	None of the above (B criteria) plus pain only in the lower abdomen	Assumption that in these patients FCT of the lower abdomen would be adequate

upper abdomen (criteria U) and positive CT findings, all had pathology restricted to upper FCT. Among those with symptoms from only the lower abdomen (criteria L), however, there were five cases that had pathology in the upper abdomen in concomitancy (three cases) or not (two cases) with findings from lower FCT.

Figure 1 illustrates one of these cases. The patient with appendicitis and symptoms from only the lower part of the abdomen (L criteria) had CT finding only in the upper part of the abdomen (upper FCT). Figure 2 shows another patient with multiple abscesses that were thought to be due to appendicitis. One tiny abscess is found in the upper FCT, while all the rest of abscess formations are seen only in lower FCT. One can argue, however, about the clinical relevance of the tiny abscess present on upper FCT and whether that could influence the treatment.

## Discussion

Our study demonstrates that there is a good correlation between the location of the pathology as suggested by clinical information on the CT request form and the location of the pathology.

This was most obvious in patients with symptoms from the upper abdomen only (U criteria). If FCT only had been performed within this group, no mistakes would have been done, and no important diagnoses missed. The reason for

this is probably due to lack of symptoms in the lower abdomen and pelvis from diseases in the upper abdomen. For example, gallbladder problems are known for causing shoulder pain [9], commonly known as referred pain [10]. On the other hand, it is not common for pain referred from upper abdomen to lower abdomen.

Another explanation could be that we used clearer signs than those used to define criteria L, for instance, jaundice and elevation of serum amylase levels.

We can probably conclude that in patients with symptoms similar to those with criteria U, the CT can be focused to upper part of the abdomen without loss of essential information. This way, the radiation dose to radiation-sensitive organs such as the ovaries would be reduced [11]. Unfortunately, this was the smallest group in our study (29 out of 189 patients, i.e., 15%), which mandates larger studies to confirm our results.

The largest group in our study (53%) was the one with symptoms consistent with criteria B, i.e., which we believed necessitated imaging of the whole abdomen–pelvis. In case of prospective studies, it might be possible to have more patients with criteria U or L. Only 8% of patients with criteria B had pathology on both upper FCT and lower FCT. This is however the reality we face, with requests sometimes not encompassing all data. Probably, more careful localization of symptoms prior to CT and better information in the requests would allow reduced radiation exposure exams (FCT) to be used more often.

**Table 2** Verified pathologies demonstrated on CT

Diagnosis	No. of cases	Location of pathology	Comments
Duodenal ulcer	2	Upper FCT	Confirmed with endoscopy
Cholecystitis	3	Upper FCT	Confirmed by surgery/histopathology
Appendicitis or tumor of the appendix	24	1 upper FCT 2 both lower and upper FCT, 21 lower FCT,	Confirmed by surgery or follow-up for 15-31 months; one patient had carcinoid of the appendix without metastases
Pelvic inflammatory disease (PID)	3	2 Lower FCT, 1 No CT findings	Confirmed by gynecological examination
Diverticulitis	8	Lower FCT	No cancer was shown on colonoscopy and follow-up
Trauma	15	7 contusions in upper FCT (2 spleen, 1 liver, 3 kidney, 1 rib).  Others without any pathologies	None of the patients demonstrated any pathology in lower FCT, except one patient with spleen rupture who had small amounts of fluid in the lower FCT not essential for diagnosis Confirmation was with surgery and/or follow-up
Pancreatitis	4	Upper FCT	Confirmed by history, laboratory tests and follow-up
Abscess without any other pathologies	1	Lower FCT	Confirmed by puncture and follow-up
Postoperative abscess	5	4 lower FCT, 1 upper FCT	Confirmed by puncture and follow-up
Abscess secondary to PID	1	Both lower and upper FCT	Confirmed by puncture and follow-up
Ileus because of Crohn's disease	2	Both lower and upper FCT	Known Crohn's disease; confirmed by puncture and follow-up
Peritoneal carcinomatosis	1	Both lower and upper FCT	Previously unknown tumor; confirmed by puncture and follow-up
Kidney stones ± hydronephrosis	5	Both lower and upper FCT	All demonstrated distal stones and hydronephrosis; confirmed by history, puncture, cystoscopy, urography or follow-up
Pyelonephritis	2	Both lower and upper FCT	Confirmed by laboratory tests and follow-up
Local recurrence of tumor	1	Lower FCT	Confirmed by puncture and follow-up
Strangulated bowel wall hernia	1	Missed on CT.	Missed on CT
Bleeding in kidney cyst	1	Upper FCT	Final clinical diagnosis; no abnormalities during follow-up
Perforated urinary bladder	1	Lower FCT	Extravasation of instilled contrast agent
Ovarial torsion	1	Lower FCT	Surgery

**Table 3** Other diagnoses or findings that could not be confirmed by radiological, surgical, or histopathological findings

No. of cases	Comments
1	Patient with Crohn's disease; the clinical assessment was relapse of Crohn's disease; CT did not reveal any findings that could corroborate such diagnosis (no previous CT available)
4	Mesenteric lymphadenitis; spontaneous improvement
1	Pain likely due to badly placed intrauterine device as suggested by CT
2	Suspicion of ovarian torsion
8	Simple urinary tract infection (cystitis) with or without laboratory tests
2	Dermal infections
1	Leukemia
9	Gastroenteritis
1	Ruptured follicular cyst
1	Lumbago
1	IBS
1	Psychiatric problems

**Table 4** Correlation between suspected localization of pathological findings as suggested by the information provided in the request form and the location of pathology as shown on CT

		Location of pathology based on request form		
		B	U	L
Location of pathology on CT	No pathologic findings on CT	64	17	36
	Upper FCT	11	12	2 <sup>a</sup>
	Lower FCT	17	0	19
	Both upper and lower FCT	8	0	3 <sup>b</sup>

For definition of B, U, and L, please see the text.

<sup>a</sup>Patients with appendicitis who had CT findings only on upper FCT

<sup>b</sup>One patient with appendicitis who had multiple abscesses, one patient had pyelonephritis, one patient with ureteral stone where hydronephrosis contributed to accurate diagnosis

Even with prospective studies, “difficult” cases can be excluded initially and making generalizations difficult. Most patients with positive findings had pathology only on lower FCT.

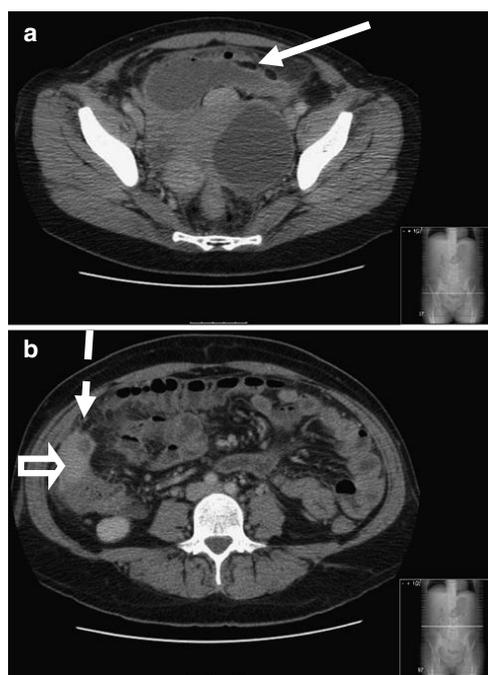
Even patients with criteria L had most pathologies only on lower FCT with or without simultaneous pathologies seen on upper FCT. An important subgroup within those with criteria L was patients with diverticulitis. Diverticulitis can be seen in all parts of the colon, even rectum [12, 13]. The most common location, however, for diverticulitis is the sigmoid colon and the descending colon. There is always the possibility of cancer being present simultaneously with diverticulitis or simulating diverticulitis [14]. Because of this, colonoscopy is used in all our patients initially thought to have diverticulitis even with CT being done. It could be argued that presence of liver metastases on CT would affect accuracy of diagnosis [15]. Colonoscopy, however, is always advocated at our center, with the



**Fig. 1** The scout image in the lower right corner indicates where in the abdomen the sectional image is from. This is an image of upper FCT (above the iliac crest). The slightly inflamed appendix (*white arrow*) can be seen *to the right behind the tip of the liver*. This patient had symptoms only from the lower abdomen (L criteria) and pathologic findings only on upper FCT

possibility of completing the diagnostic workup with an upper FCT reserved for patients who do demonstrate cancer on colonoscopy. Additionally, in the younger adult age group that we selected, the prevalence of colon cancer is much lower, especially below age 40 [16].

Patients with appendicitis are however more difficult to evaluate. Appendicitis is one of the most common diseases causing acute abdominal pain in the younger patients [17].



**Fig. 2** **a** The *arrow* indicates a large abscess due to appendicitis on this image of lower FCT. Note the scout image *to the right* and iliac bones in the main image. **b** Same patient in upper FCT showing a tiny abscess (*hatched arrow*) medial to the liver (*empty arrow*)

Different strategies have been used for reduction of the radiation dose while imaging patients with suspected appendicitis. In this setting, one study has evaluated the use of pelvic CT [18]. There are important differences between that study and ours. Kaiser, et al., only examined children with suspected appendicitis. We examined adults with all abdominal emergencies. In addition, they imaged the pelvis without contrast enhancement which could greatly influence interpretation of the results. Finally, they imaged the pelvis regardless of symptoms, only based on suspicion of appendicitis. Nevertheless, it appears that appendicitis is a difficult diagnosis based only on lower FCT. In order to circumvent this limitation, studies have been made where CT imaging was focused on the part of the abdomen where cecum was presumed to be [19, 20]. In the first study, no comparison was done between focused and unfocused CT. Still, the authors had a sensitivity of 93% and specificity of 97%. In the study by Jacobs and colleagues, focused CT was done without any contrast agent, and comparison was made with CT with both oral and intravenous contrast agents.

If one had done lower FCT on patients with L criteria, significant pathologies would have been missed in five patients. One of these was the patient in Fig. 2. Though our study did define the small abscess in the upper abdomen as an important finding, the treatment of this patient was not influenced by this finding. The patient received antibiotics and had the larger abscess drained percutaneously. The small abscess disappeared without further treatment.

In three cases, the pathology was seen exclusively in upper FCT. Two of these had highly positioned appendicitis, while the third had pyelonephritis.

In our population, there were no patients with disease of the aorta; this could be due to the age span in the group [21]. We decided to image the whole abdomen–pelvis in patients with suspected kidney stone because of the length and course of the ureter.

The number of negative cases in patients with criteria B, L, or U did not differ, ranging from 59% to 64%.

All patients with abdominal trauma had findings only on upper FCT [22]. Patients with more severe trauma are usually imaged more extensively. These patients, where only abdomen–pelvis had been imaged, have probably had less severe trauma. This, combined with the fact that in Sweden, where this study has been performed, the majority of trauma cases are due to blunt injuries probably explains why no injuries were seen in lower FCT.

An important group of patients in our population was that with feared postoperative complications. In these patients, the complications were usually at or close to the site of surgery, either in the upper or lower FCT. This probably means that imaging of the whole abdomen is not necessary when suspecting a postoperative abscess.

Other than what is mentioned above, our study suffered some limitations. One limitation is the low number of cases. The number 189 is relatively high compared to some studies, yet we looked at different conditions, and the number of cases for each diagnosis is low. However, we have intentionally included several diagnoses, believing that this is both an advantage as well as disadvantage of our study. Some authors, for instance, regard cecal diverticulitis as a false-positive diagnosis in patients with suspected appendicitis [23]. While it is true that the treatment is different, still, cecal diverticulitis has the same localization as appendicitis. To focus on diagnosis without consideration for the imaged area was not our primary objective.

In this study, we assumed that the information given in the examination request were correct and complete. Unfortunately, we do not have a way to control this aspect; however, we assume that the distribution of incorrect information and/or mistakes in the requests is stochastic and even in all groups and, therefore, would not influence the result of this study as a whole.

We also employed a complicated system for our gold standard. For instance, we had three patients who had benign liver lesions too difficult to adequately assess on CT, yet follow-up and other imaging methods such as magnetic resonance imaging and ultrasound with contrast-enhancement demonstrated the benign nature of these findings which did not demand treatment. We did not include such incidental findings which did not require treatment. Nevertheless, the patients in our study were young adults, and the likelihood of finding incidental malignant tumors was not high. With larger studies, it is conceivable that a few patients might benefit from accidental finding of tumors that would otherwise remain undiagnosed.

The radiation dose measured at our center with the 64 multislice CT used was 2.2 mSv effective dose. Of this, 1.35 mSv was, on average, given to lower FCT area, while 0.85 was given to upper FCT. If only upper FCT had been used in patients with criteria U, 61% of the radiation dose would have been reduced.

## Summary

Patients presenting with symptoms and signs of disease from the upper abdomen could be examined by focused CT, i.e., a scan limited to the upper abdomen only. In our study, this would have benefited at least 3% of the examined patients with a substantial reduction of radiation dose. Accurate clinical examinations and good information in the examination request are critical in obtaining this goal. There is, however, need for larger studies to validate these results.

In patients with symptoms and signs from the lower abdomen, however, there might be loss of significant findings if the upper abdomen is not imaged and/or better criteria have not been applied.

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II



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## PEER REVIEW

# Does Enteral Contrast Increase the Accuracy of Appendicitis Diagnosis?

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**Background** Several approaches traditionally have helped opacify the bowel when computed tomography (CT) is used to diagnose appendicitis. With the development of multidetector row CT (MDCT), the need for enteral contrast agents is less obvious.

**Purpose** The objective of this study was to evaluate retrospectively the accuracy of MDCT demonstration of appendicitis using enteral contrast agents.

**Methods** We reviewed radiologic reports of all 246 adult patients with suspected appendicitis who underwent 16-slice MDCT during 2005-2006 at our department. The use of enteral contrast agents and the route of administration were documented by one investigator. A radiologist evaluated whether the responses in the reports were consistent with diagnosis of appendicitis. The accuracy of the radiologic reports was assessed using the results of surgery, histopathology and 3 to 21 months of follow-up.

**Results** Of patients studied, 14.6% received no enteral contrast agent, 8.5% received both oral contrast and rectal contrast (enema), 46.7% received oral contrast and 30.1% received rectal contrast enemas. The accuracies for the CT diagnosis of appendicitis with different combinations of agents ranged from 95% to 100%, with no significant difference among groups.

**Conclusion** Our study shows that the accuracy for diagnosis of appendicitis by abdominal 16-slice MDCT is high regardless of enteral contrast use. Therefore, further use of enteral contrast agents for CT diagnosis of appendicitis in adults cannot be recommended.

**W**ith 250 000 new cases diagnosed in the United States every year, appendicitis is the most common abdominal emergency.<sup>1</sup> Appendicitis occurs most often between the ages of 10 and 20 years, but no age is exempt. It is more common in men, with a male-to-female ratio of 1.4:1; the overall lifetime risk in the U.S. is 8.6% for men and 6.7% for women.<sup>2</sup>

It has long been suspected that appendicitis is related to obstruction of the appendix, most commonly due to an appendicolith.<sup>3</sup> It was therefore logical to use contrast enema and fluoroscopy to diagnose appendicitis with the major diagnostic criteria being nonvisualization of the appendix<sup>4</sup> and the arrowhead sign.<sup>5</sup> Later, contrast enema was continued in combination with computed tomography (CT) examination to diagnose appendicitis,<sup>6,7</sup> and the method has

continuously been explored with published studies.<sup>8</sup> Authors of other studies began reporting using oral contrast agents.<sup>9</sup>

However, with the development of high-resolution multidetector CT (MDCT), investigators have suggested that use of enteral contrast agents is unnecessary.<sup>10</sup> The objective of this study was to evaluate retrospectively the accuracy of MDCT for diagnosing appendicitis in relation to enteral agents used.

## Methods

### Patient Population

A group of adult ( $\geq 15$  years) patients who consecutively received CT examinations to diagnose appendicitis at Karolinska University Hospital, Solna, Sweden, was selected retrospectively. Inclusion criteria included having been examined by contrast-enhanced 16-slice MDCT during 2005 and 2006 at our department and

a specific suspicion of appendicitis mentioned on the request. Exclusion criterion was having previously undergone abdominal CT.

Patients were divided into 4 groups based on use of enteral contrast agents:

- Group X: patients examined without any enteral contrast agents.
- Group O: patients examined with oral contrast agents.
- Group R: patients examined with contrast enema.
- Group B: patients examined with both oral and rectal contrast agents.

#### *CT Protocol*

For contrast enema the colon was filled with 1 L of warm tap water containing 50 mL of 2% diatrizoate meglumine (Gastrografin, Bracco Diagnostics Inc, Princeton, New Jersey) with 370 mgI/mL. This was given at the emergency department or ward 30 minutes before the examination.

For oral contrast, patients received 1 L tap water containing 30 mL 2% diatrizoate meglumine (370 mg I/mL) orally 90 to 120 minutes before the examination.

All patients received intravenous (IV) contrast agent. Injected contrast media used was Ioversol (Optiray, Mallinckrodt Imaging, Hazelwood, Missouri) with 350 mgI/mL followed by 40 mL saline flush. It was injected at a rate of 4 mL/s via a 20-gauge (diameter, 0.9 mm) IV line by a power injector. The examination was performed only in the portal venous phase.

At our hospital, radiologists decide what type of contrast agents to administer. The choice of the enteral contrast was made by the radiologist who oversaw the examinations. The customary approach at the department at the time of patient admission included the administration of contrast enema, yet some radiologists had adopted other modes for appendicitis.

The MDCT examinations were conducted on a 16-slice LightSpeed VCT (GE Healthcare, Waukesha, Wisconsin). The protocol included 2 scout images, lateral and frontal. The following imaging parameters were used:

- Detector coverage: 40 mm.
- Helical thickness: 0.625 mm.
- Speed: 55.
- Pitch: 1.375:1.
- Scan field of view: large body.
- Reconstruction type: soft.
- Kilovoltage: 120.
- Milliampereage: auto (smart mA) ranging from 150 to 350.

After the examination was completed, it was reconstructed in axial, coronal and sagittal projections with 5-mm thickness and 2.5-mm index and stored in the picture archiving and communication system.

#### *Radiologic Assessment*

The final radiologic reports were retrieved for all patients. They were divided into CT-positive and CT-negative for appendicitis (radiologist and radiologist in-training, Michael R Torkzad and Fausto Labruto, respectively). The diagnostic criteria for appendicitis were appendix diameter > 7 mm, or > 6 mm along with periappendicular inflammation.

The CT examinations also were reviewed by 1 blinded researcher (a radiologic technologist, AL) who documented which, if any, oral and/or rectal contrast had been administered. This researcher did not assess the images or the reports for the presence or absence of any pathologic conditions.

#### *Statistical Analysis*

All data are expressed as mean  $\pm$  standard deviation unless otherwise specified. The differences between each group were assessed by Mann-Whitney U test. Positive predictive value is defined as the proportion of patients with positive test results who are correctly diagnosed, and is obtained by dividing the number of true positives (TPs) by the number of TPs plus the number of false positives (FPs). Negative predictive value is defined as the proportion of patients with negative test results who are correctly diagnosed, and is obtained by dividing the number of true negatives (TNs) by the number of TNs plus the number of false negatives (FNs).

Accuracy is a measure of how well a test correctly identifies or excludes a condition, and is obtained by dividing the number of TPs plus the number of TNs by the number of TPs plus the number of FPs, plus the number of TNs plus the number of FNs. See Table 1 for a summary of statistical methods formulas.

#### *Ethical Aspects*

The study was approved by the local ethical committee, and the need for informed consent was waived because the study was retrospective and did not violate patient privacy in Sweden.

#### **Results**

A total of 246 CT examinations were reviewed during 2 years, fulfilling the inclusion criteria. All results are summarized in Table 2.

**Table 1**  
**Summary of Statistical Methods Formulas**

<b>Sensitivity</b>	$\frac{TPs}{TPs + FNs}$
<b>Specificity</b>	$\frac{TNs}{TNs + FPs}$
<b>Positive predictive value</b>	$\frac{TPs}{TPs + FPs}$
<b>Negative predictive value</b>	$\frac{TNs}{TNs + FNs}$
<b>Accuracy</b>	$\frac{TPs + TNs}{TPs + FPs + TNs + FNs}$

TP = true positives; TN = true negatives; FP = false positives; FN = false negatives.

The accuracy of the radiologic reports was assessed using surgery with histopathologic examination (n = 102), and 3- to 21-month clinical follow-up (n = 144; mean and median follow-up was 13 months, with a 25% to 75% median of 8 to 17 months) as standards of reference.

- Group O (n = 115): 26 TP diagnoses and 1 FP diagnosis were observed, whereas 87 TN diagnoses and 1 FN diagnosis were observed, accounting for 96% sensitivity and 98% specificity.
- Group R (n = 74): 22 TP diagnoses and 1 FP diagnosis were observed, whereas 51 TN diagnoses and no FN diagnoses were observed, accounting for 100% sensitivity and 98% specificity.
- Group X (n = 21): a TP diagnosis in 8 cases and no FP diagnoses were observed, whereas TN diagnoses in 12 cases and an FN diagnosis in 1 case were observed, accounting for 89% sensitivity and 100% specificity.
- Group B (n = 36): a TP diagnosis in 11 cases and

no FP diagnoses were observed, whereas a TN diagnosis in 25 cases and no FN diagnoses were observed, accounting for 100% sensitivity and 100% specificity.

A TP diagnosis of appendicitis was found in 22.6% (26/115) of patients in group O; 29.7% (22/74) of patients in group R; 38% (8/21) of patients in group X; and 30.5% (11/36) of patients in group B. A TN diagnosis of appendicitis was found in 75.6% (87/115) of patients in group O; 68.9% (51/74) of patients in group R; 57.1% (12/21) of patients in group X; and 69.4% (25/36) of patients in group B.

The 95% confidence intervals for percentage of cases with appendicitis in each group were 5% to 16% for group O; 2% to 15% for group R; 0% to 11% for group X; and 0% to 11% for group B, thus demonstrating no statistically significant differences between these groups.

Sensitivity, specificity and positive and negative predictive values in the different groups ranged between 89% (sensitivity for group X) and 100%. No statistically significant differences could be demonstrated.

The accuracies of CT with different enteral agents ranged between 95% and 100% (see Table 2).

**Discussion**

This study shows that the accuracy of abdominal 16-slice MDCT is high for diagnosing appendicitis regardless of whether enteral contrast is used, and

**Table 2**  
**Diagnosis of Appendicitis Based on Type of Enteral Contrast Used**

	Group O	Group R	Group X	Group B	Total
Number of cases	115	74	21	36	246
True positives	26	22	8	11	67
False positives	1	1	0	0	2
True negatives	87	51	12	25	175
False negatives	1	0	1	0	2
Sensitivity	96%	100%	89%	100%	97%
Specificity	98%	98%	100%	100%	98%
Positive predictive value	96%	96%	100%	100%	97%
Negative predictive value	98%	100%	92%	100%	98%
Accuracy	98%	99%	95%	100%	98%

O: oral contrast agents; R: contrast enema; X: neither oral nor rectal contrast agents; B: both oral and rectal contrast agents.



**Figure 1.** Contrast-enhanced computed tomography (CT) scan of a man examined because of suspected appendicitis; image was reformatted in the coronal plane. Despite the absence of enteral contrast medium, the inflamed appendix (white arrow) is clearly visible.

regardless of the route of administration (oral, rectal or both). These results probably reflect the high spatial resolution of modern MDCT technique and the ability to view the images in the coronal and sagittal planes using multiplanar reformatting (see Figure 1). Today diagnosis of appendicitis is based largely on direct visualization of the appendix and its surrounding areas, whereas in the past diagnosis may have been based on not being able to visualize the appendix.<sup>11-15</sup>

Positive oral contrast agents have traditionally been used in CT examinations, not primarily to visualize the bowel, but to differentiate bowel loops from low attenuating structures with potential pathology.<sup>16</sup> However, the administration of high-density contrast agents has been challenged because of difficulties visualizing the mucosal enhancement in small bowel diseases when using IV contrast techniques.<sup>17,18</sup> The role for oral agents has therefore shifted from simple demarcation of the bowel loops toward simple distention of the small intestine.

In the emergency situation, there are several problems to consider regarding the use of oral contrast agents. Even in a healthy adult, it usually takes about 1 to 3 hours for the contrast medium to reach the cecum after administration, although some researchers have succeeded in reducing this time to about 50 minutes or less.<sup>19</sup> In fact, there are several studies that have shown a clearly higher percentage of appendicular perforations in patients with appendicitis undergoing CT, which has led some authors to avoid using CT.<sup>20-23</sup> However, this high rate of perforation might be due to more difficult cases being referred to CT. Nevertheless, administration of oral contrast agents could lead to an unnecessary diagnostic delay in patients with appendicitis.

Another problem is that appendicitis and other abdominal inflammatory processes might cause a local paralysis, commonly referred to as the sentinel loop sign seen in radiographic studies.<sup>24,25</sup> This may further delay the contrast agent in passing to the cecum. Moreover, patients with appendicitis usually experience nausea,<sup>26-28</sup> which makes ingestion of large amounts of oral agents difficult.

Administration of a contrast enema has the advantage of filling the bowel with less delay than by the oral route. This procedure may be less tolerated in some patients. Filling of the colon must also be monitored to guarantee that the contrast medium has reached the cecum and appendix, which leads to an increased radiation dose to the patient (see Figure 2). On the other hand, these patients may receive a reduced radiation dose because the CT examination is limited to the cecum.<sup>7,29</sup>

Bowel opacification could be considered useful in the pediatric population and lean individuals. Theoretically, it often is difficult to image the bowels of children and lean adults using abdominal CT because they have little intra-abdominal fat separating the bowel loops. However, a series of CT studies using only IV contrast enhancement has proved the approach to be highly accurate in the pediatric age group.<sup>30-33</sup> Also, as reported in a study by Kaiser et al,<sup>31</sup> there are fewer differential diagnoses to consider as causes of abdominal pain in children compared with adults.

Lee and colleagues have compared 2 groups of patients undergoing CT for acute abdominal pain: one group without oral or IV contrast agents and one with both IV and oral agents.<sup>34</sup> However, their results cannot be directly compared with the results of this study in which patients always received IV contrast agents.



**Figure 2.** Contrast-enhanced CT image of a woman examined because of suspected appendicitis. Despite rectal administration of 2 L of contrast agent, the cecum did not fill with contrast medium because of the presence of feces in the colon. In this case, the contrast enema did not add to the sensitivity of the examination.

#### Limitations

A major limitation of this study is that it was a retrospective study with no means of controlling for "suspicion of appendicitis" and why radiologists really chose different enteral agents. These limitations are inherent in the diversity of daily work in an emergency radiology department. To reduce these problems, only patients with specific referrals for CT for appendicitis were included in this study. Moreover, only patients who, according to our records, were undergoing CT for the first time were included.

In this study, other diagnoses were not considered. This was beyond the scope of this article. If other diagnoses are to be ruled out, the need for enteral contrast agents can still be tailored for those

indications, but as far as appendicitis is concerned, the results of this study do not indicate any need for administration of enteral agents.

#### Conclusion

This retrospective study demonstrates that the use of enteral contrast media does not increase the accuracy of diagnosis of appendicitis by MDCT. Thus, when MDCT is available, the use of enteral contrast agents is unnecessary for diagnosis of appendicitis.

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III



## Accuracy of low-dose chest CT in intensive care patients

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**Abstract** In this prospective study, we set out to determine the accuracy of low-dose computerized tomography (LDCT) of the chest in intensive care patients. Fifteen adult intensive care patients were examined with a standard-dose CT protocol (average radiation dose=6.7 mSv), chosen as the reference standard, followed by a non-contrast-enhanced LDCT protocol (average radiation dose=0.59 mSv). Each examination was then read by two separate groups of radiologists blinded to both the purpose and the protocol of the study. In the small group examined, the results showed 100% accuracy in the diagnosis of pneumomediastinum, pericardial effusion, and pleural effusion, and 90% accuracy in the diagnosis of pneumothorax and consolidation. There were no false-positive findings, and the few false-negative findings were unlikely to lead to any clinical interventions. Our examination protocol, while providing a tenfold reduction of the radiation dose, nevertheless remained accurate enough for resolving certain clinical questions common in the intensive care patient. Thus, we suggest that protocols aimed at reducing the radiation dose in chest CT could be applied to the intensive care patient for resolving some specific questions, without compromising the diagnostic yield of the examinations.

**Keywords** Computerized tomography · Chest · Radiation dose · Intensive care

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### Background

Severe respiratory failure is a common indication for treatment in the intensive care unit (ICU). High-resolution imaging may provide vital information for the clinician managing these patients. Computerized tomography (CT) plays an increasingly important role [1, 2] in the setting of acute lung injury [3], and it has been demonstrated to be more effective than portable, bedside chest X-ray [4]. Compared with bedside chest X-ray, CT imaging may provide superior information in several ways. The distribution of pulmonary consolidation may tell the clinician whether the patient is a candidate for treatment in the prone position [5]; detection of pleural fluid may lead to drainage and, thus, result in improved gas exchange; and better imaging of pulmonary infiltrates may lead to an improved understanding of the etiology of the disease. During the ICU stay, repeated imaging is necessary in order to provide optimal treatment [6]. In this setting, the usefulness of the CT technique is limited by the cumulative dose of ionizing radiation [7]. Strategies aimed at reducing the dose of ionizing radiation in CT may overcome this problem. These techniques have demonstrated increasing efficiency in terms of elective imaging of the chest [8], but to date, no study has assessed the efficacy of dose reduction strategies in the critically ill ICU patient.

The drawback of dose-lowering strategies is always the decreased quality of the image, and thus, the advantages of a smaller radiation dose must always be balanced against any potential reduction of the diagnostic yield. For this reason, we wanted to compare the accuracy of low-dose CT (LDCT) to standard-dose CT of the chest in adult intensive care patients.

## Materials and methods

This was a prospective, non-randomized study approved by the regional ethical review board. Informed consent was obtained from patients or patients' next of kin.

Patients were eligible for the study if they met the following inclusion criteria: age 16 or over, currently being treated in the ICU of our hospital, and referred for chest CT. Pregnancy was an exclusion criterion.

### CT protocols

All patients underwent chest imaging on a 64-row multi-detector CT unit (Lightspeed VCT, General Electric Medical Systems, Milwaukee, WI, USA). The standard-dose CT protocol included: collimation  $64 \times 1.25$  mm, tube rotation time 0.35 s, table feed 137.5 mm/rotation, kV 120, and automatic exposure control with min/max mA 200/750. All but one patient received intravenous contrast agent.

The protocol for the LDCT scan, obtained within 10 min of the standard-dose CT scan, included: collimation  $64 \times 1.25$  mm, tube rotation time 0.35 s, table feed 137.5 mm/rotation, kV 100, fixed exposure mA 70, and no contrast enhancement (Table 1).

These values for the LD protocol were chosen subjectively based on our own experience (experiments on phantoms), as well as on the literature on the subject [8].

### Patients

Fifteen patients (11 males, four females) were enrolled in the study: six trauma patients, five patients with sepsis, two oncologic patients, one patient with postoperative complications, and one patient with cardiovascular disease. The patients' median age was 54 (range 26–83).

### Image interpretation

The reference standard was established by asking two readers, staff radiologists at our institution with 13 and 30 years' experience, blinded to both the purpose and the

protocol of the study, to independently evaluate each standard-dose CT examination. Each reader completed an evaluation form structured with yes/no questions about the presence of the following findings:

- Consolidation
- Pleural effusion
- Pericardial effusion
- Pneumomediastinum

The readers were asked to report consolidation, pleural effusions, pericardial effusions, pneumomediastinum, and pneumothorax even if they were very small.

In case of disagreement between the two readers, a third staff radiologist with 25 years' experience determined a consensus interpretation.

Moreover, the readers were asked if they deemed the resolution of the images adequate for assessing the position of chest tubes, venous and arterial lines, and endotracheal tubes and cannulas.

Thereafter, each LDCT was independently evaluated by two different readers; staff radiologists at our institution with 8 and 25 years' experience, blinded to both the purpose and the protocol of the study, following the same protocol as above.

In case of disagreement between the two readers, a third staff radiologist with 25 years' experience determined a consensus interpretation.

In addition, the readers of the LDCT examination were also asked whether they considered the overall image quality adequate for confident diagnosis in the intensive care patient. This was assessed by a score of 1 if adequate, 2 if below standard but still adequate, or 3 if not adequate.

### Radiation dose

The radiation dose for each examination was calculated by multiplying the dose-length product (DLP) reported for each examination, by the normalized effective dose (EDLP) for the chest (0.017). The absorbed radiation dose is expressed in milligrays per millimeter (mGy/mm); the radiation dose equivalent is expressed in millisieverts (mSv).

**Table 1** Parameters of the CT protocol for standard dose and low dose, respectively

Parameter	Standard-dose CT	LDCT
Collimation	$64 \times 1.25$ mm	$64 \times 1.25$ mm
Rotation time	0.35 s	0.35 s
Table feed / rotation	137.5 mm	137.5 mm
kV	120	100
mA	Variable (200 / 750)	Fixed 70
Average DLP (mGy / mm)	395	34
Average radiation dose (mSv)	6.7	0.59

*DLP* dose-length product, *mm* millimetre, *kV* kilovolt, *mGy* milligray, *mSv* millisievert, *s* second

### Data analysis

The findings of LDCT examinations were compared to the standard-dose CT examinations (used as the reference standard) for sensitivity, specificity, and accuracy. Data are expressed as absolute values/*n*; derived values are expressed as percentages.

## Results

### Radiation dose

The average DLP in the standard-dose CT examination was 395 mGy/mm, which accounts for an estimated average radiation dose of 6.7 mSv. The average DLP in the LDCT examination was 34 mGy, which accounts for an estimated average radiation dose of 0.59 mSv.

Thus, the average radiation dose in the LDCT scans was 11 times smaller than in standard-dose CT, which is comparable to about 45 days of background radiation in urban Sweden. It is also equivalent to the cumulative dose of approximately six bedside chest X-ray examinations at our institution.

All data are summarized in Table 1.

### Consolidation

Standard-dose CT showed pulmonary consolidation in all of the 30 lungs examined. With LDCT, consolidation was observed in 27 true-positive cases, demonstrating a sensitivity of 90%. Since none of the lungs examined were free from consolidation, specificity for this finding could not be calculated. Hence, the accuracy rate of LDCT was 76.6% when detecting pulmonary consolidation.

### Pneumothorax

Standard-dose CT showed pneumothorax in seven of the 30 hemithoraces examined.

With LDCT, pneumothorax was observed in four true-positive cases, demonstrating 57.1% sensitivity. No pneumothoraces were observed in 23 true-negative cases, demonstrating 100% specificity. Hence, the accuracy rate of LDCT when detecting pneumothorax was 90%.

### Pleural effusion

Standard-dose CT showed pleural effusion in 20 of the 30 hemithoraces examined.

With LDCT, pleural effusion was observed in 19 true-positive cases, demonstrating 95% sensitivity. No pleural effusions were reported in nine true-negative cases, demonstrating 90% specificity.

Hence, the accuracy rate of LDCT when detecting pleural effusion was 93.3%.

### Pericardial effusion

Standard-dose CT showed pericardial effusion in one of the 15 thoraces examined.

With LDCT, pericardial effusion was observed in one true-positive case, demonstrating 100% sensitivity. No pericardial effusions were reported in 14 true-negative cases, demonstrating 100% specificity.

Hence, the accuracy rate of LDCT when detecting pericardial effusion was 100%.

### Pneumomediastinum

Standard-dose CT showed pneumomediastinum in one of the 15 thoraces examined.

With LDCT, pneumomediastinum was observed in one true-positive case, demonstrating 100% sensitivity. No pneumomediastinum was reported in 14 true-negative cases, demonstrating 100% specificity.

Hence, the accuracy rate of LDCT when detecting pneumomediastinum was 100%.

It is noteworthy that, in seven of the 15 examined patients, all LDCT findings corresponded exactly to the standard-dose CT findings.

All data are summarized in Table 2.

### Quality of the examination

On a scale of 1 to 3, with 1 representing an examination of insufficient quality and 3 of sufficient quality, the two radiologists who read the LDCT examinations rated them, on average, 2.4.

In all cases, both readers judged the resolution of the images adequate for assessing the position of chest tubes, venous and arterial lines, and endotracheal tubes and cannulas.

## Discussion

Strategies for radiation dose reduction in CT of the chest have been extensively studied in the elective patient. In this study, we prospectively tested the accuracy of LDCT of the chest in the critically ill, adult intensive care patient.

The main finding of our study is that a tenfold reduction of the radiation dose yielded 100% accuracy in the diagnosis of pneumomediastinum, pericardial effusion, and pleural effusion, as well as 90% accuracy in the diagnosis of pneumothorax and consolidation.

However, considering the smallness of the group, calculating the accuracy in percentages could exaggerate

**Table 2** The true-positive, true-negative, false-positive, and false-negative values, with corresponding sensitivity, specificity, and accuracy for the five endpoints

	TP	TN	FP	FN	Sensitivity (%)	Specificity (%)	Accuracy (%)
Consolidation	27	0	0	3	90	–	90
Pneumothorax	4	23	0	3	57.1	100	90
Pleural effusion	17	10	2	1	94.4	83.3	90
Pericardial effusion	1	14	0	0	100	100	100
Pneumomediastinum	1	14	0	0	100	100	100

*TP* true positive, *TN* true negative, *FP* false positive, *FN* false negative

mistakes made in diagnoses. We therefore retrospectively analyzed the material in an attempt to critically review the misdiagnosed conditions and were able to observe the following:

There were three cases of false-negative consolidation among the false-negative results. However, in all three cases, the consolidations were very small, and because of their typical, dependent appearance, they were interpreted as atelectases and did not lead to any intervention whatsoever. This diagnostic mistake may be due to the fact that LDCT scan was carried out without contrast enhancement. Intravenous contrast agent improves the accuracy in the differential diagnosis of atelectasis vs pulmonary infiltration or other diseases [9].

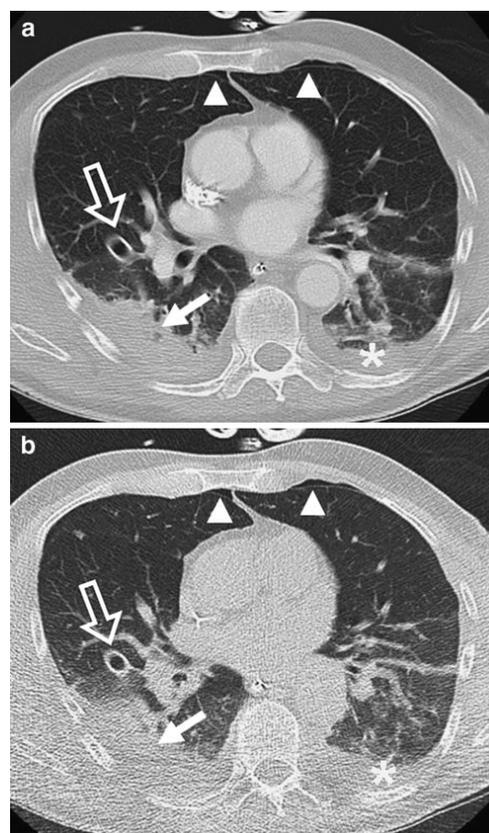
There were three cases of false-negative pneumothorax. However, in all three cases, the pneumothorax was smaller than 10 mL and was always found in the presence of a chest tube, which implies that the false-negative finding could not have clinical consequences. Interestingly, all involved radiologists were able to retrospectively identify the pneumothoraces on the LDCT scans.

Finally, there was one case of false-negative pleural effusion. However, the effusion was very small and did not warrant drainage or other intervention.

We observed two cases of false-positive pleural effusion. Again, this may be due to the absence of intravenous contrast agent, which makes it difficult to distinguish pleural effusion from pulmonary consolidation. Intravenous contrast agent improves the accuracy in the differential diagnosis of atelectasis vs pleural effusion [10].

Given the design of the study, it is not possible to judge what consequences the two false-positive findings of pleural effusion may have led to. However, it is very unlikely that these two false-positive diagnoses could lead to anything of consequence: drainage of pleural effusion is normally performed under ultrasound guidance, and this method would have rectified the false-positive diagnosis. No false-positive findings were observed for any other endpoints.

Both the blinded participants in the study judged the quality of the LDCT examination satisfactory. In particular, the participants felt confident in their ability to judge the position



**Fig. 1** CT image of the chest in the same patient examined with standard-dose (a) and low-dose (b) protocol. The small bilateral pneumothoraces (arrowheads), the lung contusion (arrow), the pleural effusion (asterisk), and the chest tube (empty arrow) can be visualized on the low-dose images, as well as on the normal-dose images

of tubes and lines, which is a recurrent clinical question in intensive care medicine. See Fig. 1 for a reference image.

Intensive care patients are usually exposed to relatively high doses of ionizing radiation [11]; this is particularly true for trauma patients [12]. We speculated that the chest diagnoses that are most common in intensive care could be made even when images have reduced resolution.

Thus, we hypothesized that the intensive care patient could potentially become the category of patient that would most benefit from LDCT protocols.

Obviously, specific clinical questions may warrant the use of standard dose protocols, notably the diagnosis of pulmonary embolism. Recent studies have addressed the question of dose reduction in chest CT for the diagnosis of pulmonary embolism [13, 14]. This, however, was outside the purposes of our study.

A limitation of this study is that many chest conditions (such as empyema and lung abscess) were not included in the evaluation protocol. We are, therefore, not able to determine the accuracy of LDCT for detection of such potentially important pathologies.

Among the conditions that were not evaluated was adult respiratory distress syndrome (ARDS). The CT diagnosis of ARDS is mainly based on the distribution of pulmonary infiltration [15]; our protocol performed fairly well on recognition of pulmonary infiltration; however, none of the examined patients had ARDS; therefore, we were not able to assess the accuracy for this specific clinical question.

Another limitation was the restricted size of the selected group. The reason for selecting only 15 patients was due to the fact that, as a result of the local ethical committee's policies, patients could be included in the study only if a next of kin could sign the informed consent beforehand, which hampered the recruitment process.

Patients participating in the study were subjected to an additional examination (the low-dose scan), which was not medically motivated and entailed an increase in the radiation dose. However, obtaining the additional low-dose scan of the chest at first examination would allow us to use the low-dose protocol on follow-up imaging of the same patient, in place of the conventional standard dose. This means that, for a patient participating in this study, the net effect would nevertheless be cumulative dose reduction during the hospital stay. In conclusion, our study suggests that, in selected clinical scenarios, adult intensive care patients could

benefit from a tenfold radiation dose reduction while still maintaining acceptable levels of accuracy in the CT of the chest.

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IV



**Low-dose chest CT versus bedside chest x-ray: advantages and disadvantages.**

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## ABSTRACT

**Aim:** In this prospective non-randomized study, we set out to compare the diagnostic yield of bedside chest X-ray (bCXR) with non-contrast-enhanced low dose chest computerized tomography (LDCT) in elderly patients.

**Methods and materials:** 16 patients (32 lungs)  $\geq 65$  years with requests for clinical bCXR were asked to undergo LDCT immediately afterwards. bCXR was performed with two views, AP (150 KV and 2.5 mAs) and lateral (140 KV and 6 mAs) with mean radiation dose of 0.7 mSv followed by a LDCT protocol (average radiation dose = 0.59 mSv). Each bCXR and LDCT examination was read on different occasions by three senior radiologists independently and blinded to all clinical information. The structured questionnaire was the same for bedside chest X-ray and LDCT images included questions about presence, measurement and subjective grading (e.g. small, moderate and large amount) of pulmonary atelectasis, pleural effusion, alveolar and interstitial infiltrate, pneumothorax, heart size and position of tubes and i.v. lines. Finally the degree of general diagnostic confidence was scored (1-4). The agreement between the results was assessed by intraclass correlation coefficient and Cohen's kappa. Other extra findings were also recorded.

**Results:** The average confidence score was always higher or the same for LDCT compared to bCXR (mean 2.85 for reading bCXR and 3.83 for LDCT). There was no discrepancy for diagnosis of pneumothorax on LDCT. On bCXR however, two radiologists missed pneumothorax in one patient while two radiologists made a false positive diagnosis of pneumothorax on two different cases. Objective measurements of atelectasis depth (ICC 0.64 vs. 0.36), depth of pleural effusion (0.74 vs. 0.27) and heart size dimension (0.82 vs. 0.43) always showed better agreement on LDCT readings than bCXR readings, respectively. Subjective categorical scoring, however, showed less difference between LDCT and bCXR. Four cases of pulmonary opacities, two cases of pulmonary malignancy, one case of skeletal metastasis to the spine, two patients with free intra-abdominal air and one case with rib fracture could be seen on LDCT only. No extra finding was missed on LDCT compared to bCXR.

**Conclusions:** our results from a small group suggest that LDCT with less radiation dose (compared to AP and lateral views) can disclose more diagnoses and shows higher objective inter-observer reliability and reader confidence. When subjective assessments are used however, there is no gain from LDCT compared to bCXR.

**Keywords:** spiral computed tomography, thoracic radiography, radiation dosage, diagnosis.

## BACKGROUND

Chest X-ray (CXR) is frequently used and applied for a large number of indications. For most ambulatory patients, chest X-ray images are obtained in the upright position. However, in patients who are unable or have difficulty standing, bedside chest X-ray (bCXR henceforth) is performed. bCXR generally comprise an antero-posterior projection, however, many institutions obtain a lateral view as well. bCXR is beneficial in several aspects: it is easy to obtain, relatively low in cost, and it exposes the patient to a low radiation dose. The American College of Radiology actually recommends as a routine, daily bedside chest radiographs for mechanically ventilated patient [1]. bCXR and ultrasound are perhaps the only imaging methods that could be performed at most departments at the patient's bedside.

The resulting images are, on the other hand, of limited quality compared to standard chest X-rays [2]. This is due to a variety of reasons: the position of the chest organs differs from when the patient is standing upright and wrinkled sheets and bed mattresses – as well as external tubes and lines and creased skin – may create artifacts. Moreover, the supine recumbent position makes it difficult to breathe in deeply. Some, if not most of the problem is of course related to the reasons why these patients need bedside chest X-ray instead of upright chest X-ray, e.g. shortness of breath or dyspnea. Hence, the patients undergoing bCXR generally cannot breathe as deeply as a typical patient undergoing upright chest X-ray.

Computed tomography (CT) represents an alternative to bedside chest X-ray, but whereas it provides optimum detection accuracy, the method involves significantly higher radiation dose to the patient. Consequently, with repeated examinations generally performed in intensive care patients the accumulated doses of ionizing radiation become a potential problem [3]. In an effort to at least partially circumvent this obstacle, we have previously demonstrated how a non-enhanced low dose CT (LDCT) protocol could reduce the radiation dose by 90% and at the same time preserve acceptable sensitivity and specificity in the diagnosis of some acute clinical conditions [4]. In this study, we set out to compare the diagnostic yield of bCXR with that of LDCT.

## MATERIALS AND METHODS

This was a prospective, non-randomized study approved by the regional ethical review committee. Patients older than 64 years who were referred for bCXR were eligible for the study. Upon signing the informed consent, the patient was examined by bCXR, followed by LDCT. Both CT and bCXR were performed by the main researcher (AL).

**bCXR:** This was done according to routines at our department and included an AP view and a lateral view of the lungs. All patients underwent bCXR on acute X-ray system (Discovery XR650, General Electric Medical Systems, Milwaukee, WI, USA) and the protocol for the bedside lungs examination. The following parameters were used for the AP view: 150kV, 2.5mAs, 1.3m FFA (Focus Film Distance) and landscape. The corresponding parameters for the lateral view were 140kV, 6.8mAs, 1.3m and portrait.

**LDCT protocol:** All patients were examined without intravenous contrast-enhancement on a 64-row multidetector CT scanner (Lightspeed VCT, General Electric Medical Systems, Milwaukee, WI, USA) within 30 minutes after bCXR. The examination parameters were: collimation 64×1.25 mm, tube rotation time 0.35s, table feed 137.5mm/rotation, 100kV, fixed exposure 70mAs. The parameters for the LDCT protocol were based on our previously published study.

**Radiation dose measurement:** The radiation dose for each CT examination was calculated by multiplying the dose-length product (DLP) reported for each examination and the absorbed radiation dose expressed in milligrams per millimeter (mGy/mm), normalized effective dose (EDLP) for the chest (0.017). This LDCT protocol results in a mean radiation dose of 0.59mSv. The radiation dose for routine bCXR was previously calculated to 0.5mSv for AP and 0.2mSv for lateral view adding up to 0.7 mSv.

**Image interpretation:** The images were viewed separately by three experienced radiologists who were blinded to the patient's history and all clinical data. The only available information was the patients' age. The bCXR and LDCT examinations were viewed in random order using a structured questionnaire covering different variables of image quality and diagnostic yield (Table 1).

**Data analysis:** Intraclass correlation coefficient (ICC) was used to estimate agreement between measurements made on either modality by the three radiologists. For subjective assessment of image quality descriptive results are shown and agreement based on Cohen's kappa for categorical variables was measured. ICC/Cohen's kappa  $\leq 0.2$  was considered poor,  $0.2 < \text{to} \leq 0.4$  fair;  $0.4 < \text{to} \leq 0.6$  moderate;  $0.6 < \text{to} \leq 0.8$  strong and  $\geq 0.8$  perfect. Bland-Altman diagram and analysis was performed for heart size measurements. 95% confidence

intervals were calculated for measured figures.

## RESULTS

**Patients:** Sixteen patients (11 males, 5 females) were enrolled into the study. Their median age was 76 (range 65 – 97). The clinical questions in the referral forms that requested bCXR were: alveolar opacities in 10 patients, pleural effusion in three, tube/catheter position in four, and pneumothorax in two. For some patients, several questions had been stated. In the following whenever conditions of pleurae and/or lungs are discussed (e.g. pneumothorax or pulmonary opacities) “cases” refers to each pleura or lung, respectively.

**Confidence in diagnosis:** On a 1 to 4 scale (see Table 1), the average confidence score was 2.85 for bCXR reading and 3.83 for LDCT reading (Table 2). The confidence score for LDCT was never below 3 and the radiologists never recommended further imaging after LDCT. In contrast, low confidence scores of 1-2 were reported for 13 bCXR readings in 7 patients (44% of patients), warranting further imaging (Table 3).

Table 1.

List of studied variables on both bedside chest X-ray and non-enhanced low dose chest CT

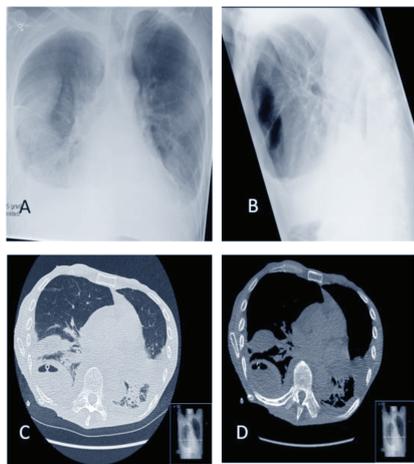
- Pneumothorax present or absent for each lung
- Atelectasis (defined as pulmonary consolidation with volume loss with or without bronchogram) for each lung
  1. None or minimal
  2. Present with a volume less than one lobe
  3. Present with a volume larger than one lobe
- The depth of atelectasis in an antero-posterior diameter wherever largest in mm for each lung
- Pleural effusion in each hemithorax
  1. None or minimal
  2. Present with a volume that probably does not demand treatment
  3. Present with a volume that probably requires treatment
- Depth of pleural effusion in an antero-posterior diameter in the deepest point of effusion in mm for each thorax
- Alveolar infiltrates (defined as alveolar filling processes, i.e. opacification of the airspaces without volume loss) present or absent for each lung
- Interstitial thickening of pulmonary septae present or absent for each lung
- Heart size
  - Maximum antero-posterior diameter in cm
  - Maximum left-right diameter in cm
- Catheters. For each catheter/tube the following had to be answered:
  - What is the catheter?
  - Where is the tip situated?
  - Are there any problems with its course?
- Other important findings
- Confidence in radiologically important diagnosis (excluding pulmonary embolism)
  1. Cannot assess. The possibility of missing a radiological diagnosis is high. Another radiologic examination should be added.
  2. Possibly correct. The possibility of missing a radiological important diagnosis is considerable and another radiological examination should be considered.
  3. Probably correct. The likelihood of missing a diagnosis is not high. Another radiological test may be considered.
  4. Confident diagnosis. The likelihood of missing a radiological important diagnosis is low and no other test is necessary.

<b>Table 2. Results of comparison of some variables between non-enhanced low dose chest CT (LDCT) and bedside chest X-ray (CXR)</b>			
ICC: intraclass correlation coefficient			
Finding	CXR	LDCT	Comments
Confidence score (1-4)	2.85	3.83	LDCT always $\geq$ CXR
Confidence score 1-2 (% of patients)	44%	0%	
Pneumothorax	<ul style="list-style-type: none"> <li>• 1 false negative by two radiologists</li> <li>• 2 false positive cases by one radiologist each</li> </ul>	No difference in assessments	Reference test: standard dose chest CT
Agreement on depth of atelectasis (ICC)	0.36	0.64	
Agreement on depth of pleural effusion (ICC)	0.27	0.74	
Heart size dimension measurements (ICC)	0.43	0.82	

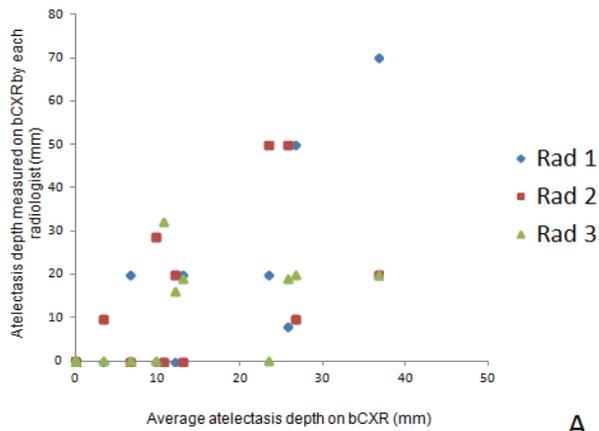
<b>Table 3. Confidence scores based on non enhanced low dose chest CT (LDCT) and bedside chest X-ray (CXR).</b>				
See table 1 for explanation.				
	CXR (3-4) by three radiologists	CXR (1-2) by one radiologist	CXR (1-2) by two radiologists	CXR (1-2) by three radiologists
LDCT score (3-4)	9	3	3	1
No case was assigned a confidence score of 1 or 2 by any radiologist upon reading LDCT.				

**Pneumothorax:** All radiologists at LDCT correctly diagnosed the only case of pneumothorax among the 16 patients (Cohen's kappa = 1). On bCXR, however, two radiologists missed the pneumothorax while two radiologists made a false positive diagnosis of pneumothorax in two different patients (figure 1) (Cohen's kappa = 0.94).

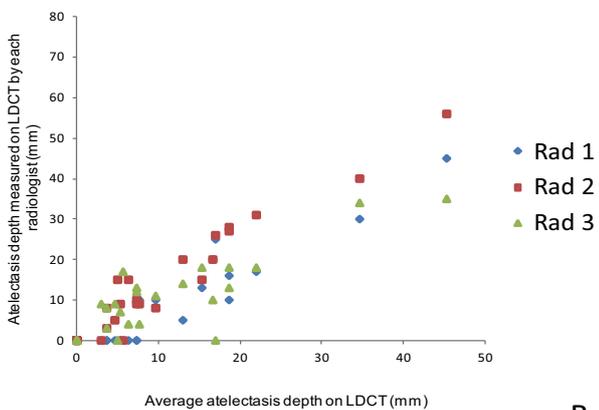
Figure 1. Patient with empyema. Two radiologists falsely diagnosed a pneumothorax at bedside chest X-ray (bCXR) on AP (a) and lateral (b) views. No pneumothorax was found by non-enhanced low-dose chest CT (LDCT) lung window setting (c) by any radiologists. The amount of pleural effusion was also more difficult to estimate on bCXR (a and b) compared to LDCT (d, same image as c but with soft tissue setting). On bCXR the radiologists scored the amount of pleural effusion from none-minimal to large and requiring (additional) drainage catheter, whereas on LDCT all radiologists concurred that on a minor amount of pleural effusion is present that does not require any additional drainage.



**Atelectasis:** There were 7 lungs on bCXR and 6 on LDCT where atelectasis assessment on a 1-3 point scale differed by a maximum of one score among the radiologists. Cohen's kappa was 0.83 for bCXR and 0.79 for LDCT, denoting strong and perfect agreements, respectively. Objective measurements of atelectasis extent, however, were much more consistent on LDCT than on bCXR. ICC was 0.36 for bCXR and 0.64 for LDCT, fair and moderate agreements, respectively (figure 2).



A

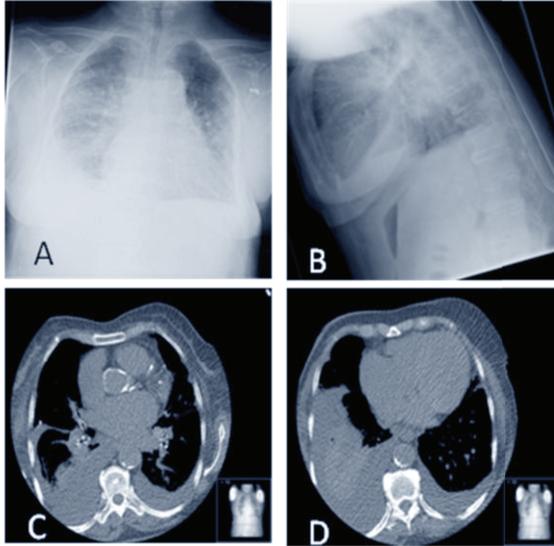


B

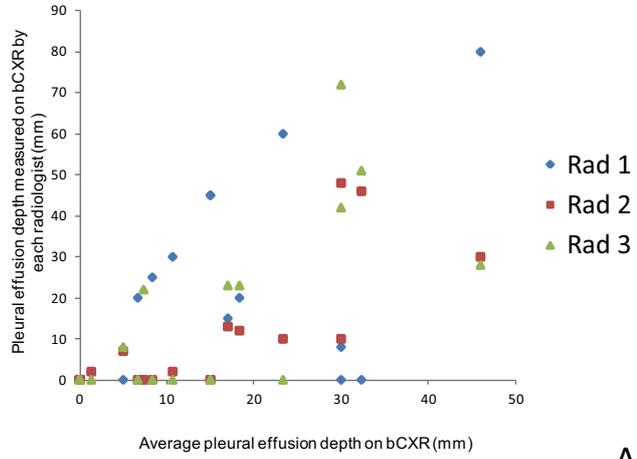
Figure 2. Correlation between atelectasis depth (mean) to measurements of by the three radiologists on bCXR (a) and LDCT (b), respectively. The measurements show better agreement on LDCT. Rad = radiologist.

**Pleural effusion:** On both LDCT and bCXR, the presence of 14 pleural effusions was assessed differently in our 1-3 point scale system. The maximum score difference was 1 on LDCT readings; by contrast, four cases showed 2 point score difference on bCXR assessment (figures 1 and 3). Cohen's kappa was 0.66 for bCXR and 0.71 for LDCT, both corresponding to strong agreement.

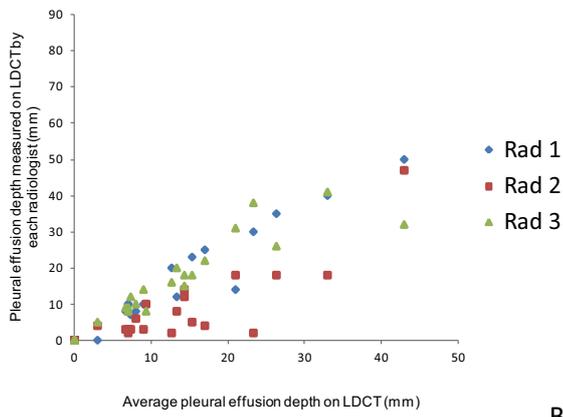
Figure 3. Patient with pleural fluid. The three radiologists disagreed on the amount of fluid in the left pleural space (scores 1, 2 and 3, respectively) at bCXR AP (a) and lateral (b) views. On LDCT with soft tissue window setting (c-d), the estimation of amount of pleural effusion was more concordant (scores 2 by all radiologists).



ICC was 0.27 for measurement of pleural effusion depth at bCXR and 0.74 at LDCT, reflecting fair versus strong agreements, respectively (figure 4).



A

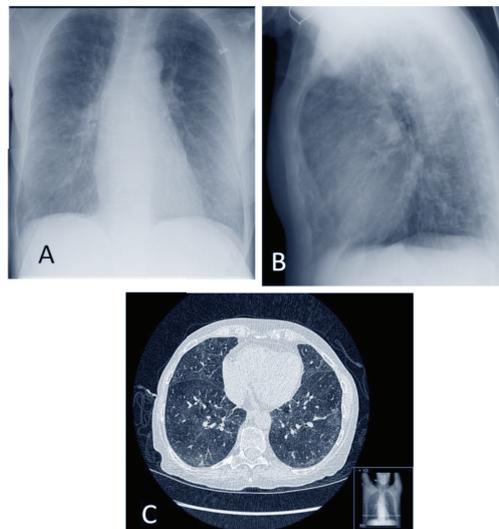


B

Figure 4. Correlation between average pleural effusion depth measurement against measurement by each radiologist on bedside chest x-ray or CXR (a) and non-enhanced low dose chest CT or LDCT (b), respectively. As could be seen the measurements lie closer to one another on LDCT than CXR. Rad = radiologist

**Alveolar opacities:** There were 8 discordant cases for bCXR and 12 for LDCT on whether alveolar opacities were present or not. The Cohen's kappa was 0.89 for bCXR and 0.71 for LDCT, perfect and strong agreements, respectively. Interestingly, 4 lungs were read as having opacities on LDCT by all three radiologists while none of them noted this finding on bCXR in any of these lungs. These four lungs were from three different patients (figure 5).

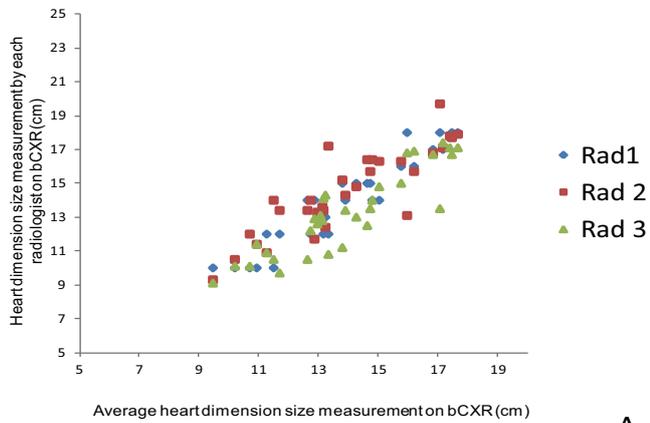
Figure 5. Neither the AP (a) nor the lateral (b) view bCXR disclose pulmonary opacities in this patient. By contrast, all radiologists noted ground glass opacities at LDCT (c).



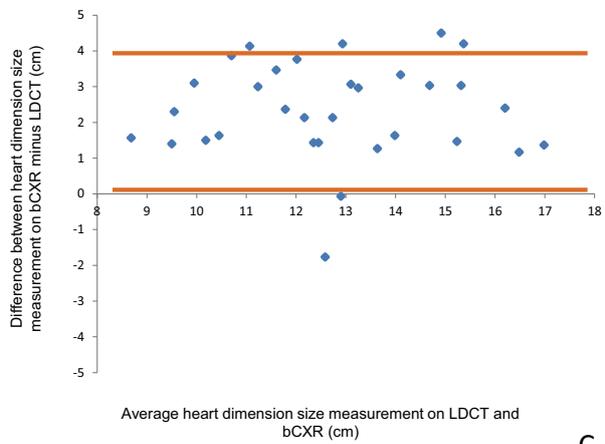
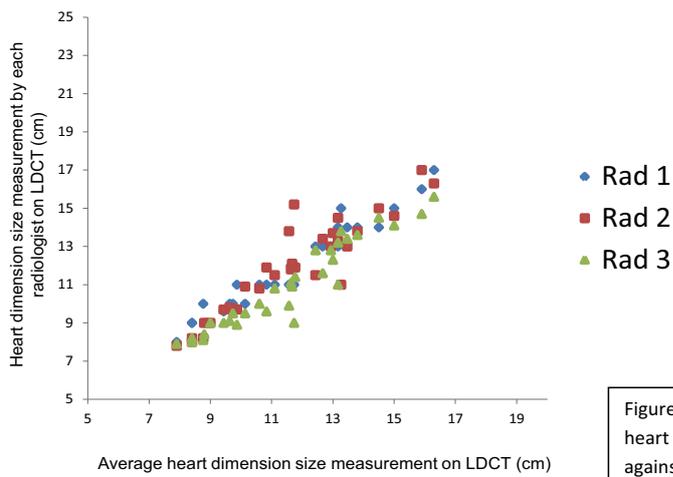
**Interstitial thickening:** there was a discrepancy among results in 15 and 19 lungs read on bCXR and LDCT, prospectively. Cohen's kappa was 0.69 for bCXR and 0.60 for LDCT, denoting moderate and fair agreements, respectively.

**Heart size:** ICC was 0.43 for heart dimension measured on bCXR and 0.82 on LDCT, reflecting moderate and perfect agreements, respectively. The graphs showing average heart

size dimension against individual measurements are shown in figure 6. The anterior-posterior diameters measured on bCXR were on average 2.5 cm larger than those measured on LDCT cm while this difference was on average 2.3 cm on left-right dimension. These dimensions were recorded higher on almost all hearts size measurements at bCXR compared to LDCT. The Bland-Altman plot shows a systemic bias with overestimation of the heart size at bCXR compared to LDCT. The 95% confidence interval of heart size measurements showed a significant 0.04 to 3.96 cm difference for bCXR (figure 6).



A

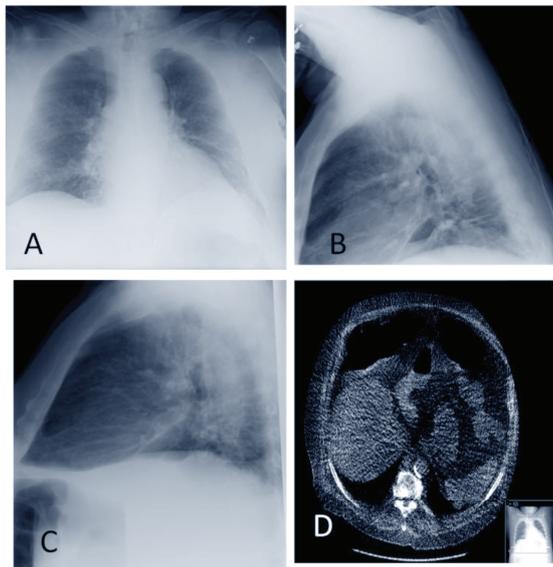


C

Figure 6. Correlation between average heart size dimension measurement against measurement by each radiologist on bCXR (a) and LDCT (b), respectively. As could be seen the measurements lie closer to one another on LDCT than bCXR. Furthermore, a systemic bias is observed by plotting Bland-Altman curve (c) showing larger measurements made on bCXR. Rad = radiologist.

**Other significant disagreements:** In two patients, pulmonary malignancy was detected by two radiologists on LDCT but was missed by all three viewers on bCXR. One case of skeletal metastasis to the spine and one case of rib fracture could be seen on LDCT only. Two patients had free intra-abdominal air, which was not detected at bCXR. One nasogastric tube was considered to be located too high by all three radiologists on LDCT but was overlooked by all three viewers at bCXR (figure 7). There were no diagnoses detected at bCXR that were missed at LDCT.

Figure 7. Mal-positioned nasogastric tube(NGT). None of the three radiologists commented on mal-position of NGT on bCXR AP (a) and lateral views (b and c). LDCT at the level of lower esophagus (d) showed however that the tip of the NGT had not reached the lower esophagus (and stomach accordingly) and needs adjustment. Interestingly the lateral bCXR view had been repeated since it did not provide adequate coverage (c).



## DISCUSSION

This study in a limited number of patients demonstrates the benefits from using LDCT compared to bCXR without increasing the radiation dose to the patient. The involved radiologists were constantly more confident when assessing LDCT than bCXR and objective measurements similarly showed higher degrees of agreement with LDCT.

Though confidence is subjective the present results are not surprising. We always expect the diagnostic yield by CT, and even LDCT, to be better than with bCXR. A previous observational study of adult patients presenting to 12 emergency departments found poor sensitivity (43.5%) for CXR among 3423 patients with acute cardiopulmonary symptoms when using CT of the thorax as the reference [5]. Moreover, 27% of pneumonias, diagnosed by CT, were overlooked at CXR in another study [6]. In yet another study, there were additional findings at CT of the thorax with impact on treatment, in 16% of patients even in those in whom CXR had suggested pneumonia [7].

The findings we looked at are perhaps the most important ones that could be assessed on non-enhanced chest CT and did not include trauma victims. One study focused on traumatic findings, such as lung contusion, hemothorax, and pneumothorax, showed large discrepancies in diagnostic yield between bCXR and CT of the thorax [8]. Atelectasis is a common finding and is important to find in the acutely ill patient. It is a well-known cause of dyspnea in adults and children [9-10] and represents a differential diagnosis in patients suspected of pulmonary embolism.

It is noteworthy that bCXR in our institution also comprise a lateral view, which theoretically should improve our assessment of pneumothorax and pleural effusion which often are located ventrally and dorsally, respectively. Consequently, with only an AP view, smaller pneumothoraces and pleural effusions can easily be missed.

Our study also suggests a better agreement among radiologists for objective measurements on LDCT compared to bCXR. It is well known that CXR, even upright, is associated with high interobserver discrepancies for different diagnoses [11]. However, with the use of qualitative assessment this advantage for LDCT was not apparent, and even slightly better agreement was in this respect demonstrated for bCXR. This is an interesting observation, the reasons for which we cannot fully explain. Though better agreement signifies robustness of the examination protocol it does not take accuracy into account. This probably explains why better agreement for alveolar opacities and interstitial thickening was found for bCXR because these findings were systematically missed by all viewers at bCXR as opposed to LDCT.

Another plausible explanation is the subjective nature of these assessments. Consequently, while LDCT provides for instance better insight into how much pleural effusion is present this does not necessarily mean that the radiologists evaluating the same volume reach the same conclusion. The real gain of LDCT may therefore be lost if a qualitative rather than quantitative assessment is used.

We also demonstrated the well-known problem of heart dimension measurements on bCXR. In a previous study, using magnetic resonance imaging as the reference, measurements were somewhat more reliable and useful on upright CXR [12]. This however may not be applicable at least to the same extent to bCXR. The overestimation of heart size at bCXR is explained by the fact that in the AP projection, the anterior chest structures are magnified because they are positioned farther from the detector compared to the PA projection of CXR obtained in the upright position. The tube-detector distance is shorter in bCXR. Consequently, measurements of other anterior structures, such as tracheal diameter, are less reliable on bCXR compared to CT [13].

According to our examination protocol, the radiation dose for LDCT was very low, actually similar to what is now called an ultra low-dose chest CT [14]. We have previously shown that LDCT can compete with normal CT [4] for the diagnosis of common chest conditions in the intensive care settings, which has also been shown for the demonstration of metastatic pulmonary nodules [15].

Our study has several limitations. The study group was small and we included only patients 65 years and older. In this age group the risk of radiation-induced cancer is less and one may use normal radiation dose CT more freely. However, we did not want to introduce more radiation, albeit low, in younger patients at this initial phase of study, hence the patient selection.

We also obtain a lateral bCXR view, for the bedside examination, which at least in our country is more an exception than the rule. Without a lateral view we would have lowered the radiation dose to the patient but probably also decreased the diagnostic yield of the examination.

bCXR is a well established examination that will probably remain the mainstay for diagnosis of many chest conditions in the nearest future. However, with the general ongoing transition from plain film studies to CT, for a variety of traditional examinations, and the increasing availability of CT scanners in the intensive care units, also CT examinations of the thorax are likely to increase.

To conclude, the observer variability is lower for bCXR, mainly because of systematic false negative results.

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# Exploring new protocols in emergency radiology, and their impact on radiation and diagnosis

Av

Ali Latifi

AKADEMISK AVHANDLING

Som för avläggande av medicin doktorsexamen vid Karolinska Institutet offentliggen  
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Karolinska Universitetssjukhuset Solna

Fredag den 15 mars 2013, kl.09.00



## Karolinska Institutet

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## ABSTRACT

Computed tomography (CT) has become the predominant radiological examination in thoracic and abdominal emergencies. The increasing use of CT, both for diagnosis and follow-up and the continued development of the CT technique demand that we improve our examination protocols constantly. The aim of this thesis has been to explore new examination protocols and to study their effect on diagnosis and on radiation dose to the patient.

Papers I and II evaluate protocol modifications of abdominal CT. In Paper I, focused abdominal and pelvic CT were assessed to find out if the examination could be limited (i.e. focused) to the area of interest based on the patients symptoms. In patients with symptoms and signs suggestive of upper abdominal disease, the results indicate that CT can be limited to this area. In patients with symptom from the lower abdomen this may, however, not be true because of the phenomenon of referred pain and CT of the whole abdomen could therefore be indicated.

In Paper II, the use of enteral contrast agent was evaluated in patients with suspected appendicitis. Enteral contrast agents administered rectally, orally or both did not differ from the diagnostic results of the protocol with CT performed without enteral contrast. Thus there is no need for delay and/or breaking the patient's fast before surgery by administration of enteral contrast.

In Papers III and IV, low dose (sometimes referred to ultra low dose) thoracic CT (LDCT) was studied. In Paper III LDCT was compared with normal dose chest CT in patients admitted to the intensive care unit and in Paper IV, LDCT was compared to bedside chest X-ray in emergency patients. Both studies demonstrated high accuracy and reliability of LDCT for diagnosis of chest disease in the emergency setting.