MDCT and MR Imaging of Acute Abdomen

New Technologies and Emerging Issues

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Editors
Michael Patlas
Hamilton General Hospital
Department of Radiology
McMaster University
Hamilton
Ontario
Canada

Douglas S. Katz
Department of Radiology
Winthrop-University Hospital
Mineola
New York
USA

Mariano Scaglione
Department of Imaging
Pineta Grande Medical Center
Castel Volturno
Caserta
Italy

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To my parents, Dr. Natan and Ludmila Patlas, to my wife Nataly, and my children Michal and Jessica.
Michael Patlas

To Darienne, my mate, my friend, my love, and my inspiration.
Douglas Katz

To Pietro and Ruben, my sons, the reason of my life.
Mariano Scaglione

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1 Evidence-Based Imaging of the Acute Abdomen: Where Is the Evidence?

Ania Z. Kielar, Cynthia B. Walsh, and Matthew D. F. McInnes

Abstract

Emergency radiology is still considered an emerging subspecialty compared to more established areas such as neuroradiology and abdominal-pelvic imaging. Although this suggests that less time has passed to allow dedicated research in imaging associated with emergency medicine, it also implies that there are opportunities for study in this field in the future.

In this introductory chapter, we emphasize the importance of evidence-based medicine in radiology and then specifically in the setting of an acute abdomen. Tools available for designing and reporting research are introduced: This includes QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies), STARD (Standards for Reporting of Diagnostic Accuracy), and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [1, 2]. We also expand on commonly accessed information currently used to help guide radiologists in diagnosis and decision making with regard to acute abdominal and pelvic conditions.

Perceived barriers to research in emergency radiology are reviewed. Tips and specific tools to implement when designing an emergency radiology research study are provided; this information may also be useful when critically appraising published literature. Finally, an overview of emerging research opportunities and innovative areas in emergency radiology research is introduced, with focus on acute abdominal conditions, all of which will be covered in more detail in subsequent chapters of this textbook.

Keywords

Evidence-based medicine · Levels of evidence
Cross-sectional imaging · Abdominal imaging
Emergency radiology

A. Z. Kielar, M.D., F.R.C.P.C. (✉)
Department of Medical Imaging, The Ottawa Hospital, Ottawa, Canada

Department of Radiology Ottawa, University of Ottawa, Ottawa, Canada

Ottawa Hospital Research Institute, Ottawa, Canada

Department of Imaging, University of Toronto, Toronto, Canada

C. B. Walsh, M.D., F.R.C.P.C.
Department of Medical Imaging, The Ottawa Hospital, Ottawa, Canada

Department of Radiology Ottawa, University of Ottawa, Ottawa, Canada

M. D. F. McInnes, M.D., F.R.C.P.C.
Department of Medical Imaging, The Ottawa Hospital, Ottawa, Canada

Department of Radiology Ottawa, University of Ottawa, Ottawa, Canada

Ottawa Hospital Research Institute, Ottawa, Canada

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Abbreviations

ACR	American College of Radiology
ALARA	As low as reasonably achievable
CT	Computed tomography
ED	Emergency department
EPs	Emergency physicians
LLQ	Left lower quadrant
LUQ	Left upper quadrant
MRI	Magnetic resonance imaging
NPV	Negative predictive value
PICO	Patient, intervention, comparison, outcome
PPV	Positive predictive value
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
QUADAS 2	Quality assessment of diagnostic accuracy studies
RLQ	Right lower quadrant
RUQ	Right upper quadrant
SAR	Specific absorption rate
STARD	Standards for reporting of diagnostic accuracy
US	Ultrasound

1.1 Background: Goals of Imaging Patients in the ED with Abdominal and Pelvic Symptoms

Imaging of patients presenting to the emergency department with abdominal symptoms has key goals of providing safe, accurate, and timely diagnoses of clinically significant abdominal and pelvic disorders. Patients with acute abdominal symptoms can have a wide range of underlying etiologies, including acute on chronic conditions. With an aging population, concomitant comorbidities may affect the emergency physician's ability to make a confident diagnosis based on physical examination alone. Increasing rates of obesity in North America and elsewhere also affect the accuracy of physical examination and lead to greater reliance on imaging. However, obesity can also negatively affect the quality of imaging, and may modify the type or modality of imaging chosen for evaluation by the radiologist [3].

Although establishing a final diagnosis is of primary concern in an emergent setting, the concept of ALARA (as low as reasonably achievable) principle should still be followed when considering imaging of patients presenting to the ED, especially those patients under 30 years of age. Radiology-initiated campaigns of "Image Wisely" in adults and "Image Gently" in children have a substantial role in emergency radiology, although imaging algorithms for assessing this patient population vary depending on the acuity of symptoms and patients' underlying level of hemodynamic stability [4, 5]. Given these principles, imaging algorithms for assessing abdomino-pelvic symptoms, and especially in pregnant patients and young patients, should begin with ultrasound, when appropriate, given that this modality is relatively ubiquitous in terms of access, is less expensive, and generally has adequate sensitivity and specificity for the diagnosis of many common acute abdominal and pelvic conditions [6]. However, in equivocal situations, in patients where ultrasound is not the imaging modality of choice (e.g., ischemic bowel evaluation), or when symptoms are discordant, MRI or CT is important for establishing a clear diagnosis.

Although there are many diagnostic tools and references available for emergency radiologists (these will be covered in subsequent chapters of this book), there are still many research questions waiting to be answered.

1.2 Perceived Barriers to Research in the Emergency Department

Patients present to the emergency department (ED) with a wide range of symptoms, signs, and underlying medical conditions. The level of acuity in this patient population varies: In many patients, urgent or emergent imaging is required, often reducing or eliminating the time needed for obtaining consent. Some patients may not be able to give consent due to reduced level of consciousness. For example, poly-trauma patients may be unconscious or hemodynamically unstable, and therefore unable to provide consent. This critical factor can be a barrier when designing research protocols, particularly for prospective studies.

Emergency departments operate 24 h a day, 365 days a year, and patients with abdominal and pelvic symptoms present at all hours. This can be a challenge to conducting prospective research, as members of the research team, including nurses and specific physicians, who are required to explain the prospective research protocols to potential study candidates, may not be present in the ED at the time consent needs to be obtained to enter a study.

Another potential barrier to research in emergency radiology is that patients who pass through the ED are usually not followed long term in the ED as compared to family practices or with other specialist physicians. The relationship between an emergency physician (EP) and patient is usually not as established as with other physicians. As a result, obtaining adequate follow-up of these patients can be difficult at times. This is particularly relevant for diagnostic accuracy research regarding determination of false-negative interpretations which often require rigorous clinical follow-up [7].

Radiologists working in the ED may either be subspecialized or work part-time in other fields and “pinch hit” in the ED. Those who work part-time in the ED often have other areas of subspecialization to which they may dedicate the majority of their research efforts. Even radiologists who are dedicated in the field of emergency radiology may find it challenging to perform certain types of research due to the nature of shift work associated with emergency radiology, coupled with the pressures of turnaround time for their final reports.

However, as we demonstrate later in this chapter, there are opportunities for research in the field of abdominal and pelvic emergency radiology which can help build upon already existing data in this growing field of imaging and intervention.

1.3 Evidence Currently Available in Emergency Abdominal Radiology

Peer-reviewed articles can be identified on numerous topics through Internet searches including Google Scholar, as well as Pubmed and many others [8, 9]. Previously published research used as supporting evidence in emergency radiology has often dealt with diagnostic accuracy of various imaging modalities to make a particular diagnosis. In some manuscripts the data included non-emergent patients, which can lead to various biases. However, more recently, “emergency-centered” or “emergency-specific” data is being published in various journals, and more recently journals specific to the field of emergency radiology have been established [10]. These publications include various types of research, including systematic reviews and single-center versus multicenter prospective studies, as well as retrospective studies, in addition to some topics which may include review articles and opinion pieces. Becoming familiar with bias in imaging research when critically appraising published articles is important. Many research efforts in emergency radiology are directed at optimizing patient outcomes, creating standardized imaging pathways, improving communication between radiologists and other physicians, as well as increasing efficiency of imaging in this patient population [10, 11].

Several resources are available to assist in assessing the completeness of research reporting and risk of bias; the tool used will depend on the study design. A large portion of imaging research is diagnostic accuracy. For this type of work, STARD 2015 can be used to assess completeness of reporting, while QUADAS-2 can be used to assess risk of bias [2, 12]. This will be described in more detail in the next section of this chapter.

Other forms of information and reference support can be accessed on the Internet. For example, the American College of Radiology (ACR) publishes Appropriateness Criteria related to numerous topics pertinent to the field of radiology which are accessible to everyone free of charge. They have organized, transparent, and reproducible methods to create their final topic development and recommendations [13]. This process utilizes structured iterative meetings of experts in the field who participate in the process of critically appraising available data and synthesizing this to develop guidelines, using the highest quality and up-to-date published data.

Within the ACR appropriateness criteria, not only is the level of supporting evidence described in the body of the text, but also the overall assigned level of appropriateness (from 0 to 9, 9 being the highest) as well as the radiation exposure related to the imaging modality and associated costs are included in tabular form at the top, for a quick overview on each topic. There has been a substantial expansion of the number of topics covered in these criteria in the past decade. They cover acute and chronic conditions, allowing a fairly robust source of support for emergency radiology [14]. For example, this website could be accessed to determine the best imaging for a patient presenting to the ED with abdominal pain and elevated lipase. Often requests for CT may be received from the ED physicians for assessment of a patient presenting with suspected pancreatitis. However, upon review of the ACR Appropriateness Criteria, unless the patient is critically ill, or if a different diagnosis is being entertained (such as ischemic bowel, in addition to pancreatitis), ultrasound is the most appropriate initial examination for imaging the biliary tract to assess for gallstones, cholelithiasis, or choledocholithiasis [15]. This type of evidence-based information helps to guide the most effective imaging for various patient scenarios.

Many other organizations, when creating guidelines or white papers for their various specialties, refer to levels of evidence when making a specific recommendation (e.g., the American Thyroid Association (ATA), the Society of Gynecology of Canada (SOGC)) [16, 17]. Describing specific levels of evidence helps to understand how to weigh different sources of information when making health-care-related decisions. Typically, higher levels of evidence have more rigorous study designs (e.g., systematic reviews rather than case reports), as well as higher quality and reliability of evidence. Creation of guidelines with indications of levels of evidence is an area of potential future work in the field of emergency abdominal and pelvic radiology.

In addition to guidelines and "white papers," various decision-support tools are also being developed through different venues, to help radiologists, clinicians, and surgeons to choose the most appropriate imaging for their patients. Some of these are available online, while others are being integrated into computer physician order-entry programs [18]. Some early publications have shown reduction in overall imaging utilization such as for pulmonary embolism CT, and radiographs of the ankles, when decision-support tools are available for physicians to follow, compared to control groups where these support systems were not available [3]. For example, in the study by Murthy et al., implementation of a clinical decision-support tool led to almost doubling of positive CT scan for assessing suspected pulmonary emboli [19]. The authors found a substantial reduction in the use of CT for this indication when the modified Wells' score was <4. This suggests that development of decision trees and associated support tools has the potential for significant positive impact on patient care. Further study is needed to quantify the direct effects of these tools on patient care, particularly in emergency abdominal and pelvic imaging [19, 20].

1.4 Growth of Evidence-Based Medicine and Tools Available

The number of publications in scientific journals has continued to grow at an increasing pace in the past several decades [21]. However, it has been documented that not all published studies are reproducible or adhere to accepted research standards [22]. There are many factors which have been proposed for this, including ones which pique the public's interest, such as the lack of research ethics approval, conflicts of interest on the part of drug companies, and even fabrication of results. However, a more common aspect of the problem facing legitimate researchers is that for a long time, no specific standards were available [23, 24]. As a result, key information was often poorly reported, thus diminishing potential usefulness of a research project.

As a goal of improving quality of medical publications, the concept of evidence-based medicine was pioneered at McMaster University in Canada and Oxford University in the UK in the mid-1990s and also applied to evidence-based imaging studies [24]. This concept incorporates research evidence, along with clinical expertise as well as patient values. The process of evidence-based medicine (and imaging) is based on five steps:

1. Ask a clinically relevant and answerable question
2. Search relevant medical literature and identify publications relevant to the topic
3. Critically appraise this literature
4. Summarize the evidence
5. Apply this evidence to clinical and imaging practices [25]

However, even with these steps in place, the various methods employed to answer a particular question have often been difficult to confidently determine. Also, the type of information to include in the methods sections and results is not always clear. It is very important that all published research, including research in the realm of emergency radiology, be reported fully, and transparently to allow readers to assess the strengths and weaknesses of the investigation. Given these various barriers that have existed for a long time, efforts have recently been made to address some of the concerns: specifically, various standards have now been developed and enhanced over time. Two such examples, which are particularly pertinent to imaging research, are STARD and PRISMA [26–28].

Many journals with high-impact factors, including Radiology and the Journal of Magnetic Imaging Resonance, now strongly encourage and in some cases even require authors to fill out checklists according to standardized tools, including STARD and PRISMA, before submitting a manuscript for review [26, 29, 30]. Reviewers use these templates to ensure completeness of the reporting such that all important factors that might contribute to bias be evident. It is therefore essential for radiologists to be familiar with these systems.

The STARD (Standards for Reporting of Diagnostic Accuracy) statement was initially developed to improve the quality of reporting diagnostic accuracy results, such as are often being evaluated in radiology publications. This tool consists of a checklist of 30 items, and a flow diagram which authors can use to ensure that all relevant information is present [26]. These items consist of essential elements of diagnostic accuracy research (e.g., index test, in sufficient detail to allow replication; whether reader of the index test was blinded to the reference standard) which allow for assessment of risk of bias and applicability.

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was developed as a tool for authors who are reporting systematic reviews and meta-analyses [28]. A systematic review attempts to collate all empirical evidence that fits prespecified eligibility criteria to answer a specific research question. This type of work should use explicit and systematic methods with the goal of minimizing bias. A properly conducted systematic review should provide reliable findings from which conclusions can be drawn and decisions made. This type of manuscript is considered high level of evidence as per the Cochrane Library. This is currently considered the preferred way of reporting items for systematic reviews and meta-analyses. Like STARD, PRIMSA also has a specific checklist to follow; this one includes 27 items which help guide creation and reporting of systematic reviews. Since many imaging systematic reviews are related to diagnostic accuracy, and these have particular methodologic challenges, a forthcoming extension of PRISMA for test accuracy systematic reviews (PRISMA-DTA) may be of particular relevance [31–33].

QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies) is another tool that can be used to assess the quality of and bias in primary diagnostic accuracy studies, if systematic reviews on a topic are not available [2]. This tool comprises four domains including patient selection, choosing the index test, choosing a reference standard, and optimizing flow and timing. Each domain is assessed in terms of risk of bias, and the first three domains are also assessed in terms of concerns regarding applicability. Signalling questions are included to help judge the risk of bias. The main signalling questions include the following:

1. Did the manuscript adhere to predefined objectives and eligibility criteria?
2. Were the eligibility criteria appropriate for the question being evaluated?
3. Were the eligibility criteria clearly described and unambiguous as well as appropriate based on the question being evaluated [34]?

Keeping this in mind, when reviewing and designing a study, these questions should be reflected upon to ensure that the risk of bias in results is minimized.

The QUADAS-2 tool is applied in four phases: summarize the review question, tailor the tool and produce review-specific guidance, construct a flow diagram for the primary study, and judge bias and applicability. The goal of this tool is to increase transparent rating of bias, and thereby allow better quality assessment of applicability of primary diagnostic accuracy studies [2].

For more information on reporting guidelines in general, readers are encouraged to visit the EQUATOR (Enhancing the QUAlity and Transparency Of health Research) group's website [31].

It is important to note the existence of so-called predatory journals. These are publishing business models that exploit researchers by charging publication fees to authors without providing the editorial and publishing services associated with legitimate journals [35]. It can sometimes be challenging to know which journals are in this category, both for those submitting manuscripts for potential publication and for those critically appraising literature found online. Of note, there are various websites available which publish lists of predatory journals, although these are not always kept up to date, and can change over time. One simple method to determine if a publication is from a non-predatory journal is to check if it indexed on Pubmed or Medline. Shamseer et al. published a recent article which identified 13 potential ways differentiating predatory journals from legitimate scientific publications (e.g., spelling mistakes on the website, article submission by e-mail) [36].

1.5 Setting Up a Research Project in Abdominal and Pelvic Emergency Radiology

Given the relative youth of emergency radiology as a specialty, there is a wide range of research projects which can be undertaken. This includes retrospective reviews, quality assurance and quality initiative projects, prospective studies as well as systematic reviews, meta-analyses, and smaller PICO (patient, intervention, comparison, outcome) projects. For radiology, the more pertinent construct, rather than PICO, may be diagnostic accuracy terminology of patients, index test, target condition, reference standard [37]. These various types of studies can be undertaken in a single center, or to increase sample size (and thus precision of estimate) as well as generalizability can involve multiple centers.

With respect to prospective studies, a way to ensure high quality of adherence to research standards, including development of primary and secondary outcomes, is the registration of prospective clinical trials at the outset of the study in the United States [38]. At this time there is a requirement, by law, for only certain types of studies to be registered before they start. Specifically, Section 801 of the United States Food and Drug Administration Amendments Act requires registration submission of summary results of clinical trials with ClinicalTrials.gov for certain clinical trials of drugs (including biological products) and medical devices [38]. Observational studies, such as those often performed in imaging, are not required by USA law to be preregistered, though it is still strongly encouraged. However, the International Committee of Medical Journal Editors (ICMJE) now requires trial registration

Table 1.1 Reasons for registering a research project and resultant beneficiaries

Role and purpose of registering project	Beneficiaries
Ethical obligations to participants and the research community are made public and fulfilled. Allows research boards additional information when making their recommendations about a project	Patients, research community, research ethics boards, the public at large
Provide information to potential participants and referring clinicians, so that a larger patient population can be encouraged to join a study	Patients, clinicians/ researchers
Reduce publication bias	Users of the medical literature
Clarify the context of the study, including results to journal editors prior to assigning formal reviewers	Journal editors, users of the medical literature
Promote efficient allocation of research funds, and reduce accidental repetition of a study already under way	Granting agencies, researchers

as a condition of the publication of research results generated by a clinical trial [38, 39]. ClinicalTrials.gov is a registry where organizations and individuals can provide the World Health Organization (WHO) Trial Registration Data Set required by the ICMJE, though others are also considered acceptable including www.anzctr.org.au, www.ISRCTN.org, www.umin.ac.jp/ctr/index/htm, www.trialregister.nl, and https://eudract.ema.europa.eu [38, 40–43].

There are purported benefits of such a registry, even when not mandatory, as outlined below in Table 1.1.

1.6 Areas of Current and Future Potential Research in Emergency Radiology

In emergency radiology, there are not only established tenets but also developing facets of research, all of which can also be areas of focus for future research endeavors. Many are interconnected and can be associated with various levels of evidence. Several examples, which tie into the subsequent topics covered in this book, include the following:

1. *Research investigating the value of radiology*: These areas of growing research include issues related to increasing throughput (e.g., investigations of CT protocols which do not need enteric contrast), decreasing costs (e.g., risk/benefit ratios of cross-sectional imaging of patients in the emergency department), and imaging algorithms that reduce the need for exploratory surgery or additional future imaging or intervention [44, 45].
2. *Standardization of reports and structured reporting*: This is an area of research growth throughout radiology but of particular interest to emergency radiology. Current investigations are looking to determine if structured reporting leads to faster turnaround time, if reports answer specific questions, and if they can reduce the need for additional, unnecessary follow-up imaging [46]. More research is needed to determine if this is helpful in both acute and follow-up scenarios.

Within this broad topic is the specific issue of communicating the risks of radiation from CT. This poses a particular challenge in the ED. However, the ED is a location of utmost importance to effectively and accurately discuss these risks with patients. Up to one-third of CT scans performed are ordered from the ED. Some data suggest that lifetime malignancy risk from CT may be as high as 1%, while other data are less clear [47]. Communicating the possible risks of radiation from CT to patients is therefore an important topic for emergency radiology. This poses opportunities, challenges, and avenues of work for clinical and research endeavors in emergency radiology.

Some of the barriers to effective communication of radiation risks in the ED include the urgency of cases, lack of a long-term physician–patient relationship, as well as lack of communication between emergency physicians (EPs) and radiologists. Challenges of communicating the potential risks of radiation-induced complications are substantial, both between radiologists and referring EPs, as well as to patients. Robey et al. showed that while 74% of EPs felt that radiation exposure should be discussed with patients, EPs only reported doing so with an average of 24% of patients [47]. Both patients and EPs felt that easier access to information regarding the risks of radiation is required. Data has shown that EPs and patients should discuss radiation more often in the ED. As physician uncertainty and knowledge are often primary barriers, radiologists may help to improve communication regarding radiation by helping to educate EPs [47]. A structured method to communicate these risks may help to ameliorate these barriers and could be a valuable tool.

3. *Sustainability of radiology in the era of competition with other specialties and potential changes arising from artificial intelligence (AI)* [48]*:* This includes topics of providing 24/7 coverage, including effects on patient outcomes, turnaround times, and overall costs to the health-care system, as well as sustainability within a radiology department, particularly when it is a smaller department.
4. *Investigation of new technologies pertinent to emergency radiology:* There are many areas with emerging and exciting new technologies. These include use of dual-energy CT, and MRI in acute abdominal conditions. MRI is being increasingly used in pregnant women for assessment of possible appendicitis, as well as for a growing list of intra-abdominal, gynecologic, and obstetric-related suspected diagnoses, especially if initial ultrasound is nondiagnostic.

Dual-energy CT (DECT): This topic of growing interest includes both prospective and retrospective research in the field of dual-energy CT [49].

Dual-energy CT is an emerging technique with useful applications for pathology in the abdomen and pelvis which may present to the ED. Dual-energy CT acquires images at two different energy levels simultaneously, using attenuation differences at those energy levels to obtain additional information. Some applications include virtual non-enhanced images, artifact suppression, and ability to determine composition of various materials (such as renal calculi). Several applications of DECT in emergency abdominal and pelvic radiology will be described in greater detail in other chapters of this textbook.

With DECT, the low-kilovoltage images increase contrast, resulting in decreased contrast usage and decreased radiation. This can be particularly useful in CT angiography, for the identification of subtle enhancement such as endoleaks. In addition, DECT has the benefit of reducing metallic artifact, which can be useful in imaging of patients with grafts [49, 50].

One of the emerging uses of dual-energy CT includes assessment of acute aortic syndrome. Some protocols acquire non-enhanced series, in order to more easily identify hyperdense intramural hematoma, or intimal calcifications, followed by intravenous, contrast-enhanced images. The non-enhanced images add additional radiation exposure. The virtual non-enhanced images obtained from DECT are diagnostic in approximately 95% of patients [50, 51]. The same dose reduction strategy can be applied to assessment for endoleaks in patients with prior endovascular aortic repair. While the virtual non-enhanced images are noisier, the diagnostic accuracy appears sufficient to have the potential to reduce radiation dose in the ED.

Other uses for this technology include assessment of renal calculi composition and evaluation of cystic versus solid renal masses. For example, this is particularly useful for calculi composed specifically of uric acid, which can be treated with urine alkalinization. These will be described in more detail in subsequent chapters.

5. *Reduced imaging utilization intensity, based on campaigns such as "Imaging Wisely" and "Image Gently"* [4, 5]: As introduced earlier in this chapter, this area of growing research looks at the strength of evidence to determine links between radiation exposure from imaging and future cancer development. For example, how can decision-support tools help physicians when deciding about the need for imaging of patients with acute abdominal and pelvic symptoms?

Optimization of existing technologies to reduce or limit radiation exposure is an area of ongoing research in abdominal and pelvic radiology. This includes only areas of interest in the images as well as the use of lower dose CT protocols. In terms of limiting the area of interrogation, this can be considered in young patients with suspected appendicitis, when initial ultrasound is unable to identify the appendix: although this topic is still controversial in the literature, a CT following a nondiagnostic ultrasound can be optimized to reduce radiation dose in this patient population by excluding the upper aspects of the abdomen which are not of clinical interest based on the presentation symptoms [52].

1.6.1 Lower Radiation Dose CT in Emergency Radiology

Lower dose CT (LDCT) may play an important role in the ED, due to the high volume of CT, and the young age of some of the patient population. One of the greatest barriers to LDCT is the lower signal-to-noise ratio, with resulting decreased confidence of interpreting radiologists. Some areas in which LDCT has shown promise include assessment for acute appendicitis. One study showed high specificity and positive predictive value for acute appendicitis [53]. Lower radiation dose renal colic CT scans are now being used relatively routinely in the ED [54].

Various radiation dose reduction strategies for CT imaging will be further elaborated upon in subsequent chapters of this book.

Summaries of already accrued evidence, including some of the associated strengths and weaknesses of current research evidence, will be covered in subsequent chapters, based on intra-abdominal and pelvic organs of concern. When interpreting currently published research however, it is important to maintain a critical thought process and evaluate the quality of the evidence provided.

Conclusion

The most up-to-date evidence related to imaging of acute abdominal and pelvic conditions in the emergency setting will be explained in subsequent chapters. As outlined in this chapter, there are new and growing areas where research in the ED setting has potential to grow. Although potential barriers to research exist in particular in emergency radiology compared to other subspecialties in imaging, with the use of organized and meticulous methodology to set up a research project, these can be completed successfully in ED radiology.

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2 Radiation Dose Reduction Strategies for Acute Abdominal and Pelvic CT

Samad Shah, Faisal Khosa, and Savvas Nicolaou

Abstract

Since the inception of CT, its use in the emergency department (ED) has increased rapidly, raising concerns about potential risks of radiation exposure to patients, particularly the pediatric population. Therefore, radiologists should adhere to the ALARA principle, to ensure that imaging examinations are clinically indicated and to keep the radiation dose to a minimum. A substantial radiation dose reduction in abdominal and pelvic CT performed in emergency patients is achievable using the strategies described below while maintaining an acceptable level of diagnostic image quality.

Keywords

CT · Radiation exposure · Strategies · CT parameters · Iterative reconstruction

2.1 Introduction

The introduction of computed tomography (CT) has transformed diagnostic radiology. Since the inception of CT in the 1970s, its use has increased rapidly for all body parts and across all ages. CT use has increased by nearly 600% in the past decade, including its use in the emergency department (ED) setting [1, 2]. It is an increasingly utilized imaging modality for ED patients with abdominal and/or pelvic pain, in an estimated 8% of adult and adolescent ED visits [1, 3]. However, with diagnostic power comes the potential risk associated with ionizing radiation exposure. Although controversial, models implicate CT-related radiation in up to 2% of cancers in the USA, and the estimated lifetime attributable cancer mortality from abdominal CT is 1 in 700 at birth, and 1 in 5000 by age 35 [3]. Therefore, radiologists should adhere to the ALARA ("as low as reasonably achievable") principle, which is particularly important in the pediatric population. The primary components of the ALARA principle in CT are to ensure that the examination is clinically indicated, and to keep the radiation dose as low as possible, without compromising diagnostic quality. Examples of organ doses from various imaging examinations, including CT, are shown in Table 2.1.

In response to concerns about medical radiation, radiologists and manufacturers have implemented many examination protocols, software, and hardware modifications to reduce CT radiation dose [4, 5]. The purpose of this chapter is to describe the techniques used to manage and minimize abdominal and pelvic CT radiation dose in clinical practice.

S. Shah, M.D. • F. Khosa, M.D., F.R.C.P.C
S. Nicolaou, M.D., F.R.C.P.C (✉)
Vancouver General Hospital, University of British Columbia, Vancouver, BC, Canada
e-mail: savvas.nicolaou@vch.ca

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Table 2.1 Typical organ radiation doses from various imaging examinations

Study type	Relevant organ	Relevant organ dose (mGy)
PA chest radiograph	Lung	0.01
Screening mammography	Breast	3
Adult abdominal CT	Stomach	10
Neonatal abdominal CT	Stomach	20

2.2 Strategies

2.2.1 Before the Scan

2.2.1.1 Clinical Decision Rules

Acute abdominal/pelvic pain can be due to multiple causes [6], including appendicitis, bowel obstruction and/or ischemia, diverticulitis, cholecystitis, renal colic, pancreatitis, and gynecological disorders. The medical history, physical examination findings, and laboratory tests are the starting point, and are usually enough to diagnose and treat patients with milder signs and symptoms. In the remaining patients, they can give clues as to the nature and location of the causal process; however, they often yield nonspecific differential diagnoses which need to be narrowed or confirmed with imaging [6]. Such tests should ideally provide either substantial positive or negative information for therapeutic decisions. A positive result establishes a diagnosis, and/or its etiology and location, and it allows for staging of its severity. A reliable negative result promotes an early discharge from the ED, avoiding admissions and unnecessary expenses.

Educating referring providers and patients about the appropriate indications for an abdominal/pelvic CT examination is a critical aspect of the ALARA principle. Recent literature calls into question the use of CT in a variety of contexts, including seizures, chronic headaches, and suspected pulmonary embolism without a moderate-to-high pretest probability, and particularly questioning its use as a primary diagnostic tool for the acute abdomen in children [3]. Several educational tools are available on the Internet that can help guide referring clinicians in ordering the most appropriate imaging examinations, particularly the American College of Radiology (ACR) Appropriateness Criteria [7].

Radiologic consultation and decision support tools may help clinicians order CT for a particular clinical indication, or help recommend alternative imaging examinations including ultrasonography (US) or magnetic resonance (MR) imaging, which do not use ionizing radiation. Web-based computerized radiology order entry systems with real-time decision support for referring physicians [8] provide an appropriateness score based on clinical indications when the clinician submits a request for a relatively expensive imaging examination (MRI, CT, and nuclear cardiology). This has been shown to decrease the growth of outpatient CT volume despite an increase in outpatient clinical visits [9].

2.2.1.2 Patient Transfer and Duplicate Studies

Often duplicate imaging examinations are ordered at the time of patient transfer from one hospital to another. At Vancouver General Hospital, where the authors of this chapter work, examinations performed at outside hospitals (OHs) are imported into a patient's medical record, which usually obviates the need to immediately repeat the examination. Software programs, including Newton, LifeImage, and Mass, allow outside CT examinations to be imported into a patient's medical record. Sodickson et al. showed that importing image CDs at the time of transfer to a level I trauma center led to a 29% reduction in repeat CT examinations compared with historical controls [10].

In case of pediatric trauma, CT examinations should not be performed at an OH when a patient is being transferred for treatment, according to the Advanced Trauma Life Support (ATLS) recommendations [11–13]. Many pediatric patients already have had CT examinations performed at OHs before being transferred to a level I pediatric trauma center for specialized care [14, 15]. These examinations are often repeated at level I facilities for reasons including poor image quality, inadequate imaging, inability to upload the images to the computer system, or change in a patient's clinical condition [16]. Liepert and Cochran (2011) found that 61% of transferred trauma patients have CTs performed at both an OH and then at level I facilities. Forty-eight percent of these were of the same body area [16]. Ultimately, repeat imaging is usually associated with delays in patient care, increased cost, and increased exposure to ionizing radiation [13].

2.2.1.3 Use of Other Imaging Modalities Based on Location of Pain

Diagnostic management of acute abdominal and pelvic differs from one country or institution to another, with two major trends: early use of CT or clinical examination, complemented with radiography and/or US, with CT on request [17, 18]. Although the former option seems to improve diagnostic accuracy, prospective studies have not shown any significant differences compared with other measures [18]. Most clinical guidelines indicate that the most appropriate imaging examination depends on the location of the pain, with ultrasound being the primary choice for the right upper quadrant and the pelvis, and CT for the remaining quadrants. Laméris et al. attained maximum sensitivity with minimal radiation dose, beginning with abdominal radiography, followed by US and CT in patients with uncertain diagnoses [17].

The location of pain or tenderness is usually a helpful starting point. The American College of Radiology (ACR) has developed Appropriateness Criteria to aid physicians in ordering the most appropriate imaging examinations for specific clinical conditions.

Right Upper Quadrant

Acute cholecystitis is the primary diagnostic consideration in this patient group. The ACR Appropriateness Criteria recommend US as the initial imaging examination for patients presenting with right upper quadrant pain [19]. Although cholescintigraphy has been shown to have slightly higher sensitivity and specificity for diagnosis, US is preferred as the initial examination due to greater availability, shorter examination time, absence of ionizing radiation, morphologic evaluation, confirmation of the presence or absence of gallstones, evaluation of the bile ducts, and identification or exclusion of alternative diagnoses. CT or MRI may be helpful in equivocal patients, and may be used to identify complications of acute cholecystitis. In pregnant patients, when ultrasound findings are inconclusive, MRI is the preferred next examination [19].

Right Lower Quadrant

Acute appendicitis (AA) is the most common cause of acute right lower quadrant (RLQ) pain requiring surgery [20]. The ACR Appropriateness Criteria recommend CT as the initial imaging examination of choice for nonpregnant adult patients presenting with RLQ pain [20]. However, in children, US is the preferred initial examination. In pregnant women, US is favored initially, with MRI as the next imaging examination when US is inconclusive, which is the vast majority of such patients [20].

Left Upper Quadrant

CT is currently the primary modality used for imaging patients with acute left upper quadrant (LUQ) pain [21]. The subperitoneal compartment and peritoneal spaces of the LUQ are vital anatomic features in understanding the imaging appearance of acute diseases in this region. Disorders of the stomach, spleen, pancreatic body and tail, and colonic splenic flexure are encountered in patients with acute LUQ pain.

Left Lower Quadrant

Acute sigmoid diverticulitis is the most common cause of acute left lower quadrant (LLQ) pain in adults. Diverticulitis is often diagnosed clinically without imaging, but imaging should be considered if the diagnosis is unclear or if complications (e.g., abscess, fistula, obstruction, or perforation) are suspected. The ACR recommends CT as the initial imaging examination for the evaluation of LLQ pain [22].

2.2.1.4 Adult Females

US is the imaging modality of choice for the evaluation of pelvic pain in female patients, especially

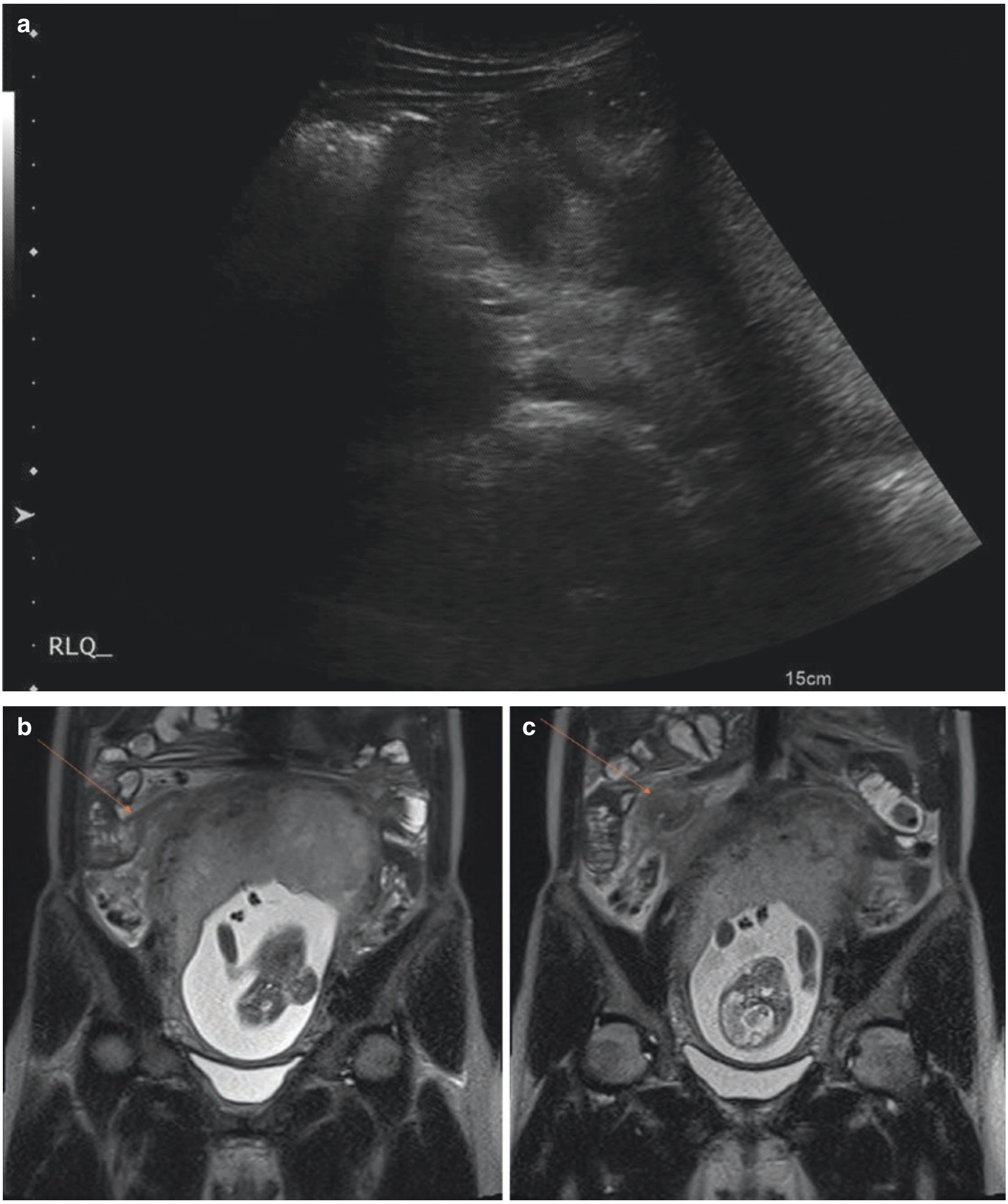

Fig. 2.1 (**a**) US of the RLQ in a 20-week pregnant woman. The appendix was not visualized. Subsequently, MRI of the abdomen was performed. (**b**) Coronal T2 fat-saturation images show a dilated appendix arising from the cecum with adjacent fat stranding (orange arrows), representing acute appendicitis. 20-week intra-uterine gestation is also noted

if gynecological pathology is suspected. MRI is being increasingly used as a problem-solving tool in pregnancy (Fig. 2.1), and as a follow-up examination to reduce patient radiation exposure. Occasionally, CT will be performed after equivocal US or after US to further evaluate the findings [23].

2.2.1.5 Pediatric Population

The recent increase in the use of CT in the pediatric population is largely caused by the advent of fast helical and then multi-detector CT [24], which reduces the need for sedation [25]. Pediatric patients represent a relatively small fraction of the overall number of patients undergoing CT examinations. The combination of higher radiation doses to children for a given CT examination, and a much larger lifetime risk per unit dose of radiation, could potentially result in a significantly higher lifetime cancer mortality compared to adults. In the USA, at least 600,000 abdominal/pelvic and head CT examinations per year are performed on children less than 15 years old, and of these individuals approximately 500 may, at least theoretically, eventually die from a cancer attributable to the radiation from the CT [26]. The dose delivered in most pediatric CT examinations could be reduced by decreasing the milliampere-seconds (mAs), either manually or automatically, and by increasing the pitch [26].

2.2.1.6 Role of Conventional Radiography (CR)

CR is widely available and has been the initial imaging examination of choice for the evaluation of patients with abdominal and/or pelvic pain. However, recent studies have shown that it has limited diagnostic value for assessing abdominal/pelvic pain, and that the results infrequently change patient management [27]. Conventional radiography is appropriate for a select group of patients. It has been shown to have good accuracy for the diagnosis of suspected bowel obstruction, perforated viscus, and foreign bodies [28].

2.2.2 During the Scan

Once the decision has been made to perform a CT examination, there are many available strategies to reduce radiation exposure.

2.2.2.1 Eliminate Unnecessary Phases

It is vital to critically examine the significance of each phase in a given CT protocol. For instance, in patients with undifferentiated abdominal pain, many practices have historically performed additional pyelographic phase scans of the kidneys with the rationale that this provides additional free information. This additional acquisition usually adds approximately 30% of the radiation dose from full abdomen/pelvis scan, for very low incremental clinical yield. Similarly, in protocols for suspected mesenteric ischemia, non-contrast phase could also be eliminated, thereby eliminating this additional radiation exposure [4].

2.2.2.2 Patient Size

Small patients absorb fewer of the incident X-rays than larger patients, so to maintain similar image quality lower X-ray tube output is needed in smaller patients. The pediatric radiology community is the forerunner in this concept [29], but the general principle also holds for adult patients, as well as for imaging various body parts, particularly the extremities.

2.2.2.3 External Shielding

If used, radiation shields must be placed after the planning scout views. Otherwise, the placement of shields before the scouts causes the scanner to compensate by increasing X-ray output to penetrate the additional detected attenuation. Proponents point to substantive dose reduction from the use of overlying shields, whereas opponents argue that the shields introduce noise and artifacts [4].

2.2.2.4 CT Parameters

Automatic Tube Current Modulation

Longitudinal (z-axis): Increasing tube current or duration of an examination (mAs) results in a proportional increase in radiation dose to the patient. Tube current modulation allows the tube current to be actively modulated during the scan along the z-axis, to more efficiently apply radiation to the patient instead of using a fixed tube current. The scanner will produce fewer X-ray photons in regions of lower attenuation (caudal chest), and will modulate higher values of tube current in regions of higher attenuation (pelvis). Modulating tube current has been reported to provide up to 40% dose reduction per examination [30]. Additionally, it is used for consistency of image quality.

Axial (x-y-axis): Axial or in-plane modulation adjusts the X-ray tube output as the gantry rotates around the patient, typically increasing mAs for lateral projections, where there is more tissue to penetrate, and decreasing mAs for frontal projections, where there is less tissue to penetrate [30]. Tube output variation can be derived using heuristic estimation methods from a single orthogonal scout view.

Tube Voltage Modification

Unlike tube current, kV has a nonlinear relationship with radiation exposure. For example, a 14% decrease in tube voltage from 140 to 120 kV will decrease radiation dose by up to 30–35% [31]. Reducing tube voltage from 120 to 100 or 80 kV often permits overall reduced exposure technique, and is advised for small- and average-sized patients [31, 32]. However, a single tube voltage level is chosen for each CT examination because current CT technology does not allow real-time modulation during the exam.

Lowering tube voltage can improve image contrast for CT angiograms, as well as other high-contrast structures, including renal and ureteral calculi, since lower voltage examinations depict the presence of iodine with a greater contrast-to-noise ratio [33, 34]. However, lowering tube voltage increases image noise, which degrades image quality. Recently, automated tube voltage-assist technology has been introduced by CT manufacturers. This software aids tube voltage selection based on the patient's attenuation profile from the CT localizer and the user's chosen examination type. Importantly, the reduced tube voltage values were found to provide diagnostically acceptable image quality [35].

Reducing *z*-Axis

When evaluating a specific diagnosis such as acute appendicitis (AA), a focused CT which is limited to the lower abdomen and pelvis rather than a complete abdominal and pelvic CT scan is one way to limit radiation exposure. Several studies in adults suggest that focused CT examinations have similar diagnostic results compared to complete CT examinations while substantially reducing the overall amount of radiation to which the patient is exposed [36]. However, CT targeted to the tender region of the abdomen or pelvis may potentially have an unacceptably high rate of misdiagnosis [37]. Further prospective study is warranted to determine the diagnostic utility of partially visualized pathology, and clinical outcomes.

2.2.2.5 Low-Radiation-Dose CT

It is possible to tolerate increased levels of image noise when assessing intrinsically high-contrast structures, including renal and ureteral calculi as noted, in which reduced mA can be used. Interestingly, studies have also shown suitability of low-dose CT for assessment of low-contrast disorders, including suspected diverticulitis and AA [38–42]. However, CT is often acquired to assess or exclude many other differential diagnoses in clinical practice. In addition, these examinations had severely compromised image quality compared to standard-dose CT and did not evaluate diagnostic performance.

Subsequently, Othman et al. showed acquisition of high-quality CT images at low radiation doses with comparable diagnostic performance to standard-dose CT images using a combination of 100 kVp imaging, intermediate tube current levels, and model-based iterative reconstruction in the general setting of acute abdominal pain, regardless of the suspected clinical diagnosis [43]. However, prospective evaluations are needed utilizing low-dose CT in routine clinical practice.

2.2.3 After the Scan

2.2.3.1 Image Reconstruction Algorithms

Different mathematical algorithms are used to reconstruct images from the raw CT data. Unlike adjusting CT parameters, including kVp and mAs, reconstruction algorithms do not directly affect radiation dose, but rather help reduce noise, which consequently allows implementation of lower dose.

The first commercial CT scanners used filtered back projection (FBP) techniques because of its faster reconstruction and ease of implementation [44]. However, FBP does not permit reduction of radiation dose while trying to improve image resolution. To address some of these concerns, scanner manufacturers have introduced newer image reconstruction algorithms—namely, iterative reconstruction techniques.

Iterative Reconstruction

Iterative reconstruction techniques iterate the image reconstruction several times to better estimate mathematic assumptions, therefore requiring longer computational time and robust computers. The common endpoint of all current iterative reconstruction algorithms is to produce lower image noise and higher resolution by maintaining edges and lower artifacts [44]. This enables use of reduced-dose CT. Studies have shown lower image noise for abdominal CT at radiation doses lower than FBP [45–47]. Singh et al. showed lower image noise and improved diagnostic confidence for abdominal CT at 8 mGy with adaptive statistical iterative reconstruction (ASIR) compared with a standard dose of 17 mGy with FBP [45].

Third-Generation Iterative Reconstruction

The first and second generations of iterative reconstruction algorithms enabled dose reduction by up to 40–60% compared with FBP techniques for some clinical applications [48, 49].

A new third generation of iterative reconstruction algorithm, the model-based iterative reconstruction (MBIR), was recently developed and offers the possibility of a large reduction in image noise while improving spatial resolution (Fig. 2.2). Recent clinical studies showed MBIR to be useful in abdominal and pelvic CT examinations [50, 51]. A prospective study showed that the use of MBIR allowed a substantial reduction in dose for abdominal CT imaging by approximately 84%, compared with a standard-dose ASIR 50%, without a conspicuous deterioration in image quality [51].

2.2.3.2 Reconstruct with Smoother Kernels

Use of smoother kernels reduces image noise versus bone algorithm. The unavoidable compromise is in the loss of fine edge detail. However, this may be a helpful strategy to salvage noisy images, including those obtained in obese patients [52].

2.2.3.3 Reconstruct at Larger Slice Thickness

Image noise is proportional to the square root of the slice thickness. Therefore, decreasing slice thickness produces more noisy images, and causes automated tube modulation to increase mAs. Therefore, one should use caution in acquiring thinner slices, if they are not truly needed for the diagnostic task at hand [4].

2.3 Dual-Energy CT (DECT)

A few studies have investigated the radiation dose delivered by DECT compared to single-energy CT (SECT), with varying results. Wichmann

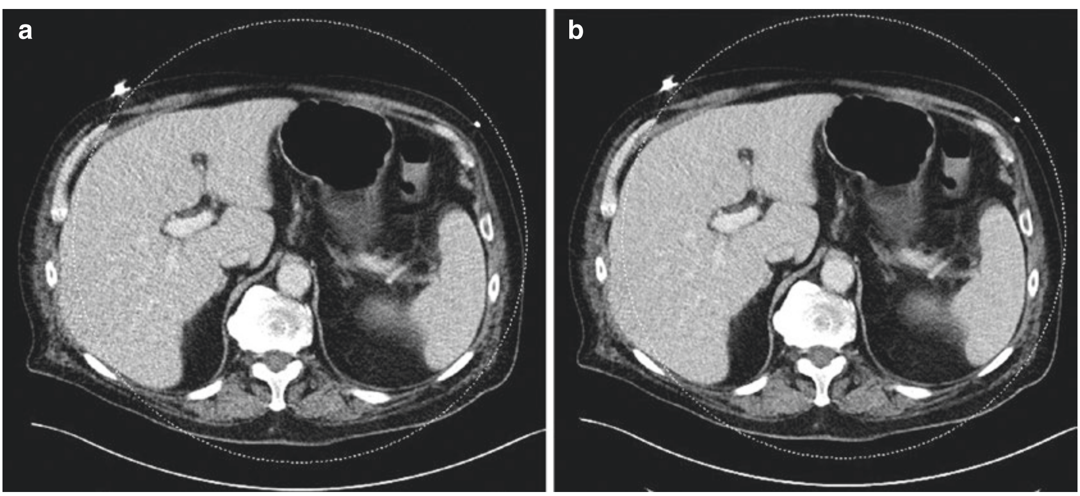

Fig. 2.2 Axial CT images at the level of the right portal vein without (**a**) and with (**b**) advanced modeled iterative reconstruction (ADMIRE). Image **a** is more noisy compared to **b**, subjectively. Both images were acquired using the same CT parameters (mA 149) at 3 mm in soft-tissue kernel

et al. showed that DECT can be performed without radiation dose penalty or impairment of image quality compared to SECT [53]. In contrast, Purysko et al. observed a significant decrease in radiation dose with DECT compared to SECT in patients who underwent abdominal second-generation SECT and DECT for hepatocellular carcinoma screening [54]. Large-scale prospective studies need to be conducted to compare radiation doses between DECT and SECT for various protocols and body parts.

2.4 Monitoring Radiation Doses

It is highly recommended to analyze dose trends with a departmental safety committee composed of radiologists, physicists, and technologists. Many authors now have their CT equipment connected to the ACR dose registry [55]. The ACR issues quarterly reports comparing CT parameters, including CTDIvol and DLP by examination type and scanner for one's institution, and compares a particular practice's averages to US national averages.

Dose tracking software can identify outliers within a department or practice by CT scanner and examination type. By setting alerts if radiation dose thresholds are exceeded, quality metrics can be maintained in a retrospective fashion. If outlier results are identified, then the examination can be reviewed by the site to determine if the protocol was followed and correct technique was used [30]. It is important to create a departmental culture to monitor image quality and examination dose (Fig. 2.3).

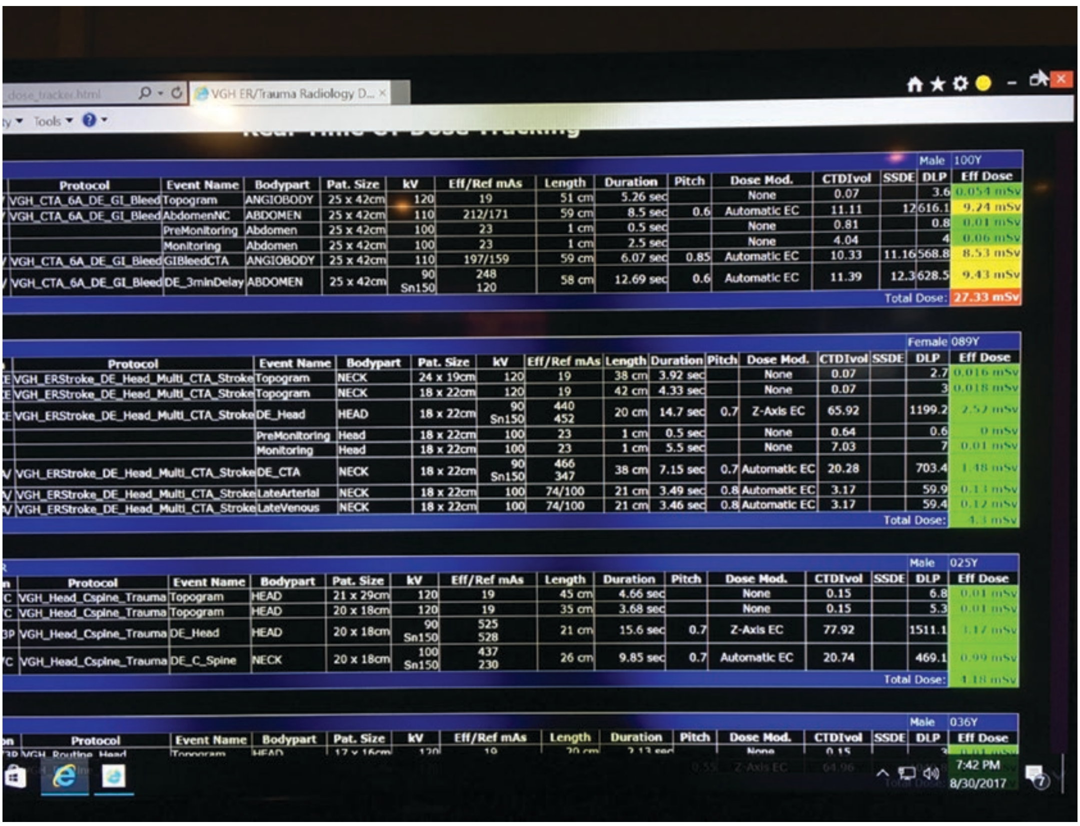

Fig. 2.3 Real-time dose monitor in the emergency radiology consultation room at the authors' institution. For each patient, the number of examinations, patient size, and CT parameters are shown. Left side of the screen containing patient demographics was cropped