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"Strengthening implementation of the justified and optimized use of ionizing radiation in medicine"

Pillars of Radiation Protection of Patients in Computed Tomography

Guidelines on Justification and Optimization

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FOREWORD

These guidelines provide in a single publication information on applying principles of justification and optimization in CT practice for the most common types of examinations. The main target audience are radiologists, technologists and medical physicists who work with CT modality. The aim of this publication is to improve radiation protection for patients undergoing CT examinations.

Clinical indications or reasons are pivotal in justifying imaging and optimizing radiation doses. Although advances in CT technologies have reduced the associated radiation dose, the appropriate use with justified clinical indications or reasons remains the best pathway to eliminate unnecessary radiation doses, reduce healthcare costs, minimize the risk of detecting incidental findings with unclear consequences, and avoid side effects from contrast injections.

Among all medical imaging tests, CT is the single largest contributor to collective radiation dose to the patient population.

Thus, clinical indication-based dose optimization is important to ensure that radiation doses are as low or as high as reasonably required and achievable to ensure uncompromised diagnostic information. A low-dose examination without required diagnostic information for a stated clinical indication or reason must be avoided as much as a higher-dose examination.

While subjective demand for image quality and imaging phases varies tremendously, all users must follow the principles of justification and optimization when it comes to the use of any medical test, including CT scanning.

Publication was developed by Dr Mannudeep K. Kalra, Attending Thoracic Radiologist at Massachusetts General Hospital and Professor of Radiology with Harvard Medical School and principal researcher in CT technology, radiation dose reduction, and artificial intelligence applications in medical imaging. Dr Anushree Burade, a post-doctoral research fellow in the department of radiology at Massachusetts General Hospital and Harvard Medical School, contributed significantly to the research based on her research experience in CT radiation dose and artificial intelligence in medical imaging.

Scientific secretary and technical officer of the project was Dr Vesna Gershan radiation protection specialist in the IAEA. Dr. Gershan played a key role in developing the concept, content, and organization of the document.

The names of the RER9157 project counterparts are listed on the last page of the guidelines.

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1. INTRODUCTION

The principle of justification balances the benefit of diagnostic information from an imaging procedure against the risk from associated radiation dose. Justification emphasizes using radiation-based imaging when the associated radiation risks yield net benefit from imaging-derived diagnostic information in the exposed individual [1-7]. A justified imaging exam provides beneficial medical information that outweighs potential radiation risks. Conversely, an unjustified imaging exam provides non-relevant information and cannot offset potential radiation risks from an unnecessary examination. Appropriate clinical indications for imaging form the backbone of justification in medical imaging.

Appropriateness is a key element in the justification of diagnostic imaging, and it is frequently used interchangeably with justification. The American College of Radiology (ACR) defines appropriateness as an evidence-based merit of the risk-benefit ratio of imaging procedures [1-5]. The ACR has published a comprehensive list of guidelines as the ACR Appropriateness Criteria, to help radiologists and referring physicians make informed decisions regarding the imaging tests most likely to yield the required diagnostic information for various clinical indications [8-10]. Unlike justification, the appropriateness criteria cover both radiation and non-radiation-based imaging. Despite guidelines on justification and appropriateness, the United States Food and Drug Administration (FDA) estimates that 20-50% of CT examinations in the US are unnecessary [11].

Avoiding unnecessary examinations based on the principles of justification and appropriateness eliminates radiation dose, while using the same clinical information to adapt scan acquisition factors helps optimize radiation dose for CT. Clinical indication-based optimization should enable users to apply as low or as high radiation doses as required to obtain sufficient diagnostic information. Optimization for CT assumes importance because CT is the single largest contributor of collective radiation dose from medical imaging [13-21]. Per the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), CT represents only 5% of radiological examinations but contributes 34% of the collective dose from medical imaging [22]. Often, variations in CT protocol and acquisition parameters result in several-fold differences in associated radiation doses as reported in several national and international studies [14-17, 23, 24]. Therefore, it is imperative to apply best practices in justification and optimization when using CT. We review the importance of clinical indication-based justification and optimization of radiation doses in CT.

2. CLINICAL INDICATION OR REASON FOR CT

Contrary to justification and appropriateness, there is no known definition of clinical indication or reason for ordering or requesting an imaging examination. A clinical indication or reason for ordering CT might pertain to the stated clinical information that a referrer describes when requesting a CT examination. In the absence of unstated, incorrect, or non-specific clinical information, radiology personnel, either CT technologists, radiology trainees (a resident or fellow), or an imaging physician can obtain information from patients, referrers, or through patients' medical records.

The stated clinical indication can represent a structured, rigid text or code (such as from an International Code of Disease) selected from a radiology order entry system list of options. It

can also come as free digital or handwritten text from the referrer. A correct and comprehensive clinical indication or reason for an ordered imaging exam is more important to judge its justification and appropriateness than its form of communication. Thus, specific clinical indications such as “staging for colon cancer,” “left lower quadrant pain,” “evaluate renal colic,” and “liver mass in this patient with cirrhosis” are more important than “abdominal pain” or “schizophrenia” for ordering an abdominal CT. Such specific indications help determine the justification (CT justified for the first three indications; liver protocol MR better than CT for the liver mass). The specific indications also help in CT protocol and radiation dose optimization (staging for colon cancer: single phase, contrast-enhanced abdomen-pelvis CT; left lower quadrant pain: single phase, contrast-enhanced abdomen-pelvis CT; evaluate renal colic: low-dose, non-contrast abdomen-pelvis CT; and liver mass in this patient with cirrhosis: when MR not available or possible, multiphase, contrast-enhanced abdomen CT).

Along with the clinical indication, other information such as patients’ age and ancillary factors also affect justification such as in patients with right lower quadrant pain or suspected appendicitis where ultrasound and MRI are the first- and second-line investigations before CT in pediatric and pregnant patients. Patient size likewise can also have a profound implication such as in morbidly obese patients where for the same age and indication, a CT might be the first modality of choice [25].

2.1. DEFINING SUFFICIENT CLINICAL INDICATION

Tofighi et al. reported from their Delphi study survey that at least 12.6% of radiologists faced at least one lawsuit that was preventable with information in the imaging requisition [26]. The Reason for exam Imaging Reporting and Data System (RI-RADS) provides a standardized evaluation of the quality of communication and information present in the referral for an imaging request. It can potentially reduce such inconsistencies in the referral imaging requests [26-30]. The RI-RADS evaluates clinical information in three categories, including impression (working diagnosis or differential diagnosis), clinical findings (signs, symptoms, location and chronicity of findings, and relevant laboratory values, medical or surgical history), and main diagnostic questions (to exclude, confirm, stage, follow-up, or assess treatment response of working or known diagnosis). The four grades of RI-RADS depend on the availability of these three categories: Grade A (adequate: all three categories of information are provided), Grade B (Barely adequate: contains all information except some missing clinical findings), Grade C (Considerably limited: only two categories of information provide), and Grade D (Deficient: only one or no category of information is provided) [27].

Evaluation of 673 clinical requisitions for medical imaging examinations reported that only 23.6% had adequate or Grade A RI-RADS information for the ordered medical imaging tests. In contrast, over 50% of clinical requisitions were completely limited or deficient [27]. Although RI-RADS represents a comprehensive quantitative method of assessing the quality of provided clinical information, its implementation would likely require mandates or regulations.

2.2. ROLE OF JUSTIFICATION IN IMAGING

Justification can help decrease unnecessary need and frequency of radiation dose-based medical imaging examinations. Such a decrease can help reduce radiation dose in some patients and

imaging practices with overuse. For example, a patient with an incidental 5 mm lung nodule on chest CT without recent malignancy or risk factors of lung cancer does not need a follow-up chest CT due to the low probability of cancer. For sites with underutilized medical imaging, justification can also increase the need and frequency of radiation-based imaging tests based on the medical need for diagnostic information that cannot be obtained in a timely manner with other tests and imaging techniques. For example, another patient with a 5 mm lung nodule on baseline CT and a substantial smoking history would need a follow-up chest CT in 12 months [30]. With active or recent malignancy history within the past 5 years, the 5 mm lung nodule would require a follow-up chest CT at 3, 6, 9, 12, and 24 months to ensure stability and exclude metastatic etiology which has a bearing on cancer stage and treatment strategy [30]. Justification can bring the clinical context and personalization of care without denying or delaying testing where and when there is a justified need and avoid testing where radiation dose risks outweigh the probability of diagnostic information augmenting patient care.

Wider availability and expanded use of radiation-based medical imaging have resulted in staggering statistics, contributing to more than 99.9% of radiation exposure worldwide [31]. A discussion on radiation-related cancer with medical imaging procedures is beyond the scope of this document. Here, we reiterate that unnecessary use of radiation-based imaging increases the risk of unintended radiation-related risks, including that of radiation-induced cancer [32, 33]. Such increased radiation risk warrants greater attention on the appropriate use in the face of increasing use and concerns on overuse [34]. More than 14% of Medicare Part B healthcare expenditures in the United States are related to imaging [35]. The US Centers for Medicare and Medicaid Services (CMS) mandates that all imaging requests include the current diagnosis and appropriate clinical indication for the imaging test. The mandate emphasizes that an incomplete requisition causes inconsistencies in imaging workflow and can result in financial losses [12, 37, 38]. A reduction in redundant imaging can help reduce the waiting time and burden in imaging workflow [10].

Beyond radiation, justification can help healthcare providers select the best diagnostic test, which is most likely to provide the required information in a timely manner. An example of this scenario can be using a liver MRI for characterizing hepatic lesions on ultrasonography rather than an abdomen-pelvis CT. A chest CT is the best imaging test to characterize an incidental lung nodule on a chest radiograph instead of a follow-up chest radiograph. Avoiding unnecessary tests can also help avoid detecting "bystander or incidental findings" that may trigger additional tests or interventional procedures. Imagine a not-so-uncommon scenario of overuse with an unindicated abdomen CT instead of ultrasound in a patient with suspected cholecystitis who reports an incidental 5 mm nodule in the lower lung. The incidental lung nodule on the abdomen CT triggers a chest CT to characterize and detect additional nodules. The chest CT describes an incidental thyroid nodule, which leads to thyroid ultrasonography and a recommendation for biopsy. Due to their high sensitivity and low specificity, medical imaging reports have a high frequency of incidental findings that often require additional testing and follow-up. This also increases patient anxiety and uncertainty in medical decision-making. While detecting early incidental findings in the early stage of life-threatening diseases can result in favorable outcomes, many incidental findings are benign and require no further testing. These examples demonstrate the key role of justification in medical imaging. Justification brings its practitioners closer to the founding principle of medicine. The principle that guides healthcare providers to “Do No Harm” (primum non nocere).

Table 1. *Common clinical indications for CT, justification, and recommendations for imaging tests.*

Clinical Indication	Justification	Recommendation
Head CT		
Suspected stroke	Indicated	Non-contrast CT (hemorrhagic stroke) With contrast (ischemic)
Head trauma	Indicated	Non-contrast CT
Delayed milestones	Not first line	Brain MRI
Suspected multiple sclerosis	Not indicated	Brain MRI
Headache without signs	Not first line	No imaging in young Brain MRI - first line
Dementia	Not indicated	Brain MRI
Abdomen CT		
Renal colic or appendicitis	Variable	Children, pregnancy – ultrasound Other patients –CT
Intestinal obstruction	Not first line	Abdominal radiograph – first line
Cancer staging	Indicated	Number of phases depends on cancer
Hematuria	Indicated	Non-contrast – renal calculi With post-contrast for other etiologies
Pelvic pain	Not first line	Ultrasound
Suspected diverticulitis	Indicated	Post-contrast CT
Chest CT		
Persistent cough	Not first line	Chest radiograph – first line
Uncomplicated pneumonia	Not first line	Chest radiograph – first line
Complicated pneumonia	Indicated	Non-contrast or post-contrast CT
Suspected embolism	Variable	Pregnancy - Doppler US and VQ/CTPA Others - CTPA
Lung cancer screening	Indicated	Non-contrast CT
Diffuse lung diseases	Indicated	Non-contrast CT

[key] *CTPA – CT pulmonary angiogram; V/Q – ventilation-perfusion scan*

3. IMPLEMENTING JUSTIFICATION

There are multiple reports on the implementation and effects of bringing justification to imaging practices [2, 3, 39-43]. Having an electronic or digital radiology information system (RIS) and/or electronic medical record (EMR) aids the implementation of justification through clinical decision support (CDS) or radiology order entry system (ROE) [2-3]. Apart from selecting or specifying specific clinical indications or reasons for imaging exams, these CDS tools provide the probability or likelihood of the ordered imaging exam to obtain the required diagnostic information based on the clinical indication and patient age group (pediatric or adult). The most common example of such a CDS tool uses the American College of Radiology (ACR) Appropriateness Criteria and provides a score from one through nine [1, 2]. These criteria were developed by a panel of subspecialty experts following a review of published data and practices. Scores between one and three imply less likelihood of information and a higher probability that the risks of imaging outweigh potential clinical benefits. On the opposite

spectrum, the scores 7-9 suggest high probability and benefit from an ordered imaging exam. The middle scores of 4-6 suggest some uncertainty and probable beneficial information where imaging exams may be appropriate. The ROE-CDS system can help referrers with the appropriate choice for imaging modality, specifically, re-evaluating the chosen modality upon selection of high-cost imaging tests (MR, CT, nuclear scans). Such a web-based ROE-CDS can automatically send information related to imaging exams to the radiology departments and enable physicians to schedule a convenient appointment timeslot for imaging examinations. While the previous iterations of the US-based CDS-ROE were standalone web programs, CDS is part of the EMR (Epic) in its current version. The EMR embedding of CDS (ACR Select) allows referring physicians to place orders directly from their digital work environment [3]. In the US, the ACR Select is now integrated into the EMR in 90 % of the providers' systems [44]. Currently, the ACR repository has 221 topics and 1050 clinical variants comprising 2900 clinical scenarios [5]. In 2014, the US Congress passed the Protecting Access to Medicare Act, which mandates CDS for advanced imaging tests for outpatients covered by Medicare.

In the United Kingdom (UK), the Royal College of Radiologists (RCR) has published the iRefer guidelines for ordering evidence-based imaging examinations [45, 46]. The iRefer guidelines were created by a panel of experts from different geographies and practice types across the UK. The recent 8th edition of the iRefer guidelines includes advise on 270 clinical common indications for imaging tests [45]. These guidelines consider three aspects of medical imaging, including supporting evidence in the published literature, cost-effectiveness of the exam, and radiation doses associated with the imaging examination. The iRefer guidelines are accredited by the National Institute for Health and Care Excellence (NICE) Evidence and help referring physicians satisfy their obligations for the Ionizing Radiation (Medical Exposure) Regulations (IR[ME]R) 2017 (Great Britain) 2018 (Northern Ireland)) [47].

The RCR's iRefer guidelines make imaging recommendations in one of the four categories: indicated, specialized investigation, indicated only in specific circumstances, and not indicated. The investigations in the indicated class have the highest likelihood of meaningful information to guide diagnosis and treatment. In contrast, specialized investigations refer to complex, time-consuming, and/or intensive testing requiring discussions with a radiologist or local protocols. The "indicated only in specific circumstances" are non-routine tests for special reasons of referrer/radiologists that can help in diagnosis but can also be deferred for self-limiting abnormalities. The investigations that are not appropriate are classified under the "not indicated" category.

The Royal Australian and New Zealand College of Radiologists (RANZR) has integrated iRefer guidelines from the RCR to optimize their referral practices in Australia and New Zealand. In non-UK European countries, the European Society of Radiology (ESR) and National Decision Support Company (NDSC) have developed the "ESR iGuide", which is the CDS curated using ESR imaging referral guidelines based on the ACR Appropriateness Criteria [41, 48]. The iGuide provides appropriateness scores for different clinical indications, medical imaging tests, and the relative costs and radiation doses associated with different testing options. A recent study comparing ACR, iRefer and iGuide guidelines for CT found almost perfect agreement between the three guidelines [49].

Although most reported evidence on justification pertains to digital or web-based CDS, principles of justification can also be applied in non-digital environments. These are difficult to track within a manual system and are both tedious and inefficient. At the very least, all sites must strive to obtain the specific reason for clinical indications or reasons for the ordered medical imaging test so that an informed decision can be taken about its justification. However,

in the absence of a digital or electronic system for obtaining the clinical indications for ordered imaging examinations, imaging personnel can implement a paper-based system for ensuring that a proper clinical indication is available to ensure that there is just use of imaging tests and clinical protocols can be optimized to obtain the desired clinical information.

3.1. EVIDENCE IN FAVOR OF CDS FOR JUSTIFICATION

Multiple studies have reported on the impact of CDS in radiology and non-radiology practices [1, 2, 45, 50]. Remedios et al. have reported a 20% decrease in ordered imaging examinations with the implementation of the iRefer guidelines [45]. Sistrom et al. reported on the effectiveness of ROE-DS in the healthcare workflow, specifically in the growth rate of outpatient diagnostic imaging services over a 7-year period at a large academic medical center [51]. They observed a significant decrease in the growth rate of the scan volume across all the imaging modalities, with the maximal decline for CT and ultrasonography. Similarly, Blackmore et al. observed drop in the utilization rate of lumbar MRI for low back pain, head MRI for headache, and sinus CT for sinusitis at an academic medical center after using CDS in clinical practice [52]. Ip et al. have also reported that computerized physician order entry (CPOE), along with the decision support (DS) system, had a beneficial impact on the workflow across all the specialties and settings [53]. From the data of 4.1 million imaging studies performed over 10 years, the authors postulated that surgical specialists create the fewest electronic orders due to the reluctance to interrupt their accustomed workflow. However, they found that these specialists had the highest rate of meaningful use of electronically signed orders in the CDS system, which could serve as a point of DS exposure.

Min et al [54] reported a mean decrease in imaging orders for patients with low back pain from 23% to 18% with the use of CDS. Poeran et al found a decrease in the rate of imaging orders over the study duration with decreased frequency of inappropriate scores from 11% to 5% [55]. Likewise, Raja et al documented decreased requests for CT urography from 24% to 15% at the CDS test site versus the control site without CDS [56]. Conversely, several other studies such as from Timbie et al (2014), Moriarty et al (2015), Doyle et al (2019), and Palen et al (2019) found no significant change in the overall imaging use with CDS [55, 57-60]. A large US government-initiated multicenter study, the Medicare Imaging Demonstration (MID) study, including 140,000 imaging requisitions from over 5000 referrers, reported little change in the appropriateness of high-cost imaging tests such as CT and MR following CDS implementation [60]. While such results raise concerns over the effectiveness of CDS in bringing utilization and justification, a lack of positive change could also be related to the fact that a substantial number of MID imaging exams (94%) had no mapping to appropriateness or imaging use guidance. In other words, there were no available guidelines for most clinical indications.

3.2. CHALLENGES WITH CDS IMPLEMENTATIONS

Despite remarkable progress in the availability of evidence-based recommendations for CDS, a substantial number of clinical indications for imaging remain without CDS recommendations for imaging. This limitation likely extends to practices from non-English speaking or using imaging sites.

While point-of-order or point-of-care implementation of CDS in computerized or digitally connected healthcare is feasible and practical, in healthcare settings without electronic medical records, CDS implementation can be challenging. The lack of picture archiving and communication systems (PACS) and electronic medical records (EMR) raises challenges in the developing world due to inconsistencies in the accessibility to electrical power and internet, the lack of local area networks (LAN), unreliable data security, high software and hardware costs, poor user interface and deployment of computers in patient areas [61].

The challenge posed by the discordance between the specified clinical indication for imaging with the stated findings in medical records is not uncommon or trivial. Lacson et al. reported that 42% of stated clinical indications with EMR and PACS did not align with the healthcare provider notes, and 81% of such orders lacked relevant clinical indications mentioned in the provider notes [62]. Defensive medicine (leading to over-ordering), high patient load, and time pressures, along with unstructured EMR data, could contribute to incomplete and/or inaccurate information.

For the same reasons, an online CDS implementation in fragmented or smaller imaging sites can be logistically or economically challenging. These advantages should not, however, deter sites from implementing hand-written or manual requests and reviews of clinical reasons to adjudicate justification and select the best scanning protocol.

Another challenge pertains to the fact that most CDS come from developed countries and might not have regional or local indications. Herein, radiologists must make individual or collective decisions regarding imaging use. In such instances, radiologists and physicians must remember two basic tenets. First, the desired information cannot be acquired from lower radiation dose tests or non-ionizing radiation tests in a timely manner. Second, the information from CT will affect patient management.

The timely availability of alternative non-ionizing radiation-based imaging tests pertain to MR imaging, often superior to CT for most clinical applications in the brain, liver, and extremities. The lack of enough MR resources and its long wait time may undercut and contradict the CDS recommendations, particularly in urgent or critical settings and when the MR waiting period extends into weeks and months. Another issue with MR is also that not all radiologists and physicians are comfortable interpreting or understanding MR as compared to CT. Biloglov et al. reported a median waiting time for MR imaging as 268 days (about 9 months), substantially greater than for CT [10]. In developing countries and smaller imaging sites, the cost of MRI is a substantial limitation to its availability. A typical MRI scanner costs up to $3 million or more, making it unaffordable for hospitals located in smaller areas in developed countries and hospitals located in low- and middle-income countries. Shortage of imaging equipment, particularly for MRI and nuclear medicine, in underprivileged healthcare settings substantially increases the waiting time for imaging, often compounded by the labor shortage of medical physicists, radiologists, and radiographers [63]. For uncooperative or claustrophobic patients, the need for sedation or anesthesia further complicates the use of MR as compared to much faster CT imaging. Sedation or anesthesia is especially difficult in pediatric patients who are at a higher risk of adverse effects, over-dosage, increased length of hospital stays, and financial costs [64-66].

Although the resources for justification are widely available, there is a disparity in their accessibility and usage in clinical settings in real-time. For instance, the Phase 4 European Society of Radiology (ESR) iGuide CDS sites are in 11 European countries - Belgium, Croatia, France, Germany, Ireland, Italy, Russia, Spain, Sweden, the Netherlands, and the UK. There is

no emphasis on evaluating the usage of these justification CDS tools in developing countries [44] Awareness about justification guidelines is another hurdle in its greater adoption. A recent 2021 survey from Granata et al. revealed that only 31.2% of the radiologist respondents knew of the dedicated pediatric imaging guidelines [67].

Furthermore, Cascade et al. suggested that physicians might be reluctant to practice appropriateness guidelines since they might interfere with their independent empirical method of selecting the imaging test [38]. These issues emphasize the need to stress the importance of justification for medical students and residents early in their curriculum. Local influences and practices can also lead to resistance in adopting justification since poor compliance with optimal practices tended to occur in similar geographical areas [3].

3.3. JUSTIFICATION DESPITE ODDS: THE PRESENT AND THE FUTURE

Despite the numerous challenges associated with its implementation, adopting justification is the most rewarding effort in optimization. Justification enables healthcare personnel to facilitate what is best for the patient and that effort brings the bane of healthcare to the forefront. Justified imaging exams are the most appropriate, timely, and likely the most consequential exams in patient care. On one hand, justification ensures that the right test is done for the right patient with the right reason and at the right time. On the other hand, it helps avoid a wrong test which might not provide the needed information for patient care and might bring more harm than benefit.

Recent publications suggest that the continued developments in machine learning, artificial intelligence, and large language models can help address issues related to inconsistent and inadequate clinical explanations for ordered imaging exams [68]. Rao et al reported that ChatGPT (OpenAI) could accurately predict the single most appropriate imaging test for patients with breast pain and breast cancer screening as per the ACR appropriateness criteria [68]. Likewise, Bizzo et al reported that AI-aided CDS can help improve patient care by identifying the appropriate imaging tests and opportunities [69]. Gish et al. reported that referring physicians preferred the free text AI tool over the direct search for indications; their AI tool correctly predicted clinical indications for imaging (91.7%), and physicians adopted those indications in 57.7% of cases [70]. As these technologies evolve, develop, and get validated on larger datasets, hopefully on our planet with a rapidly expanding map of digital connectivity, they will help support and augment a wider adoption of justification in daily practices and in real-time.

3.4. RESPONSIBILITY OF JUSTIFICATION

Perhaps the most compelling question on justification pertains to its responsibility. Who is responsible for ensuring justification? Although common sense might favor the referring physicians who order imaging in the first place as the responsible party, the answer might not be a single word or medical practitioner. At the very least, the referrers have the responsibility of providing the correct and complete clinical indications for requesting an imaging test such as CT which can provide useful and powerful information but also comes with the risk of radiation dose, contrast media usage, and detection of incidental, otherwise, leave-me-alone findings that trigger further patient anxiety and testing. Armed with a digital (electronic) system

of clinical decision support (CDS), referrers can easily select the right imaging test for their patients and their clinical indications. Without a digital system, at least some involvement of radiologists can help in the justification process. For their part, radiologists, either staff or trainees, must review the clinical indications to ensure that they have correct and complete clinical information for both justification and optimization.

Digitization can help reduce the burden of this work on radiologists, but in the absence of digitized justification and exam ordering, sites can implement some rules-based manual system for radiographers to pre-screen and proceed with the examination without radiologists-in-the-loop of decision-making. For example, radiographers can proceed with CT in patients undergoing endoscopic sinus surgery, cervical spine or head trauma, patients with suspected pulmonary embolism, aortic dissection, pulmonary nodules on chest radiographs, pulmonary fibrosis, and initial staging CT for cancer work-up. This by no means implies blanket permission for non-physician radiographers, and they should consult the radiologists for patients with the same indications but with pregnancy, compromised renal functions, prior contrast allergies, and ambiguous clinical indications.

Hospital administration and healthcare regulators, like in many developed countries, including the US and the UK, must set binding rules and regulations on imaging sites to ensure that clinical indications are available and considered before imaging tests are performed. Ideally, they must also invest or assign resources to referrers and radiology personnel to implement justification. From dominant referrers, the administration and regulators must require compliance and consideration over clinical indication and justification. Likewise, from radiology, one should require an audit of available clinical indications and their use in justification.

4. HOW JUSTIFICATION INTERSECTS WITH OPTIMIZATION

Clinical indication and justification are the key in selecting the best imaging test, prescribing the correct scan protocol, and optimizing the diagnostic quality and radiation dose [71-79]. A prior multicenter study from Tsapaki et al. reported that different clinical indications for CT scanning should have different radiation doses [80]. In their study, CT coronary angiography had the highest radiation dose, whereas, for the same body region, CT coronary calcium scoring had the lowest volume CT dose index (CTDIvol) of all the clinical indications. Likewise, indications such as lung nodule follow-up CT or lung cancer screening can be scanned at lower dose, often at a fraction of the radiation doses associated with other clinical indications of chest CT such as lung cancer staging, treatment response assessment, or CT pulmonary angiography. In the abdomen, renal colic or kidney stones and screening colonography should be imaged with lower radiation doses compared to CT abdomen for liver, pancreatic, or renal neoplasms. These findings support the importance of correct and complete clinical indication beyond justification and into the practice of radiation dose optimization.

While “schizophrenia” might be the correct diagnosis of the patient, it is often not the complete clinical information for a patient referred for abdominal CT since the same patient with flank pain could be imaged with a low dose, non-contrast abdomen CT protocol for kidney stones or with constipation, abdominal fullness, and vague/generalized pain would require a post-contrast routine abdominal CT exam. Thus, referring physicians must provide correct and complete clinical indications to tailor the CT protocol from both diagnostic quality and content and radiation dose perspectives. It is important to understand that optimization follows justification

and, as a rule, cannot fix the problem of excess or optimized radiation dose associated with an exam without justification. No dose from an unjustified exam is always better than some or any dose from an optimized CT exam. However, as noted above, at times justified, imaging exams without ionizing radiation are not available or possible, and under such circumstances, optimization offers the next best opportunity to serve patients' best interests.

5. LEARNING OPTIMIZATION FROM CLINICAL INDICATION-DRIVEN CT PROTOCOLS

In the following section, we describe optimization from a practice and a practical point of view. We advocate the TRIP strategy (Figure 1).

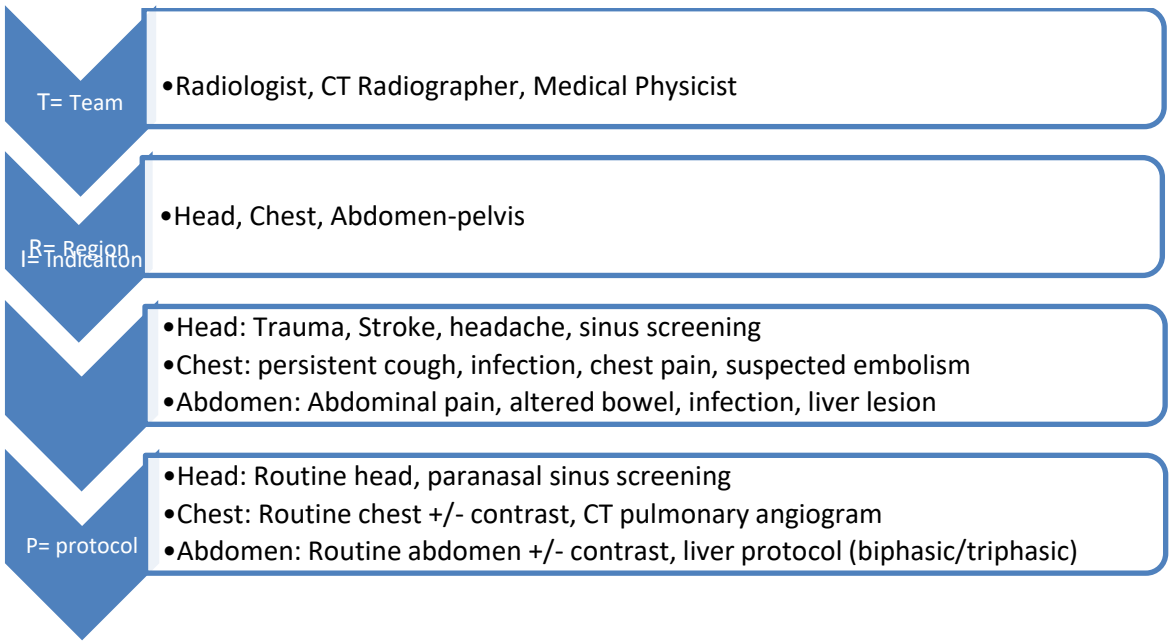

Figure 1 *Flow diagram explaining the key components of TRIP strategy for optimization.*

5.1. TEAM

The first item on the TRIP list emphasizes the vital importance of the Team behind CT protocol and dose optimization. A good Team is motivated and multidisciplinary with respect and participation from radiologists, CT radiographers and medical physicists [81, 82]. A successful change requires a motivated and skilled team. In the case of CT optimization, such a team must ideally include radiologists, CT radiographers, and medical physicists with expertise in diagnostic radiology. Each personnel have a distinctive and indispensable role in CT acquisition, reconstruction, and dose optimization. Table X summarizes roles and responsibilities of different personnel for optimizing CT acquisition factors and radiation doses.

The choice of radiologists participating in the optimization process can be based on two factors. A. Knowledge and interest: Participating radiologists must have some knowledge of the required diagnostic image quality. They must also have some interest in the process of CT

protocol creation and optimization, typically at least 1-2 times a year. B. Subspecialty: In sites with subspecialty practice, each subspecialty appoints one radiologist to make their protocol with the other team members (CT radiographers and medical physicists). Thus, a chest radiologist helps create, adjust or update chest CT protocols, and a neuroradiologist works on neuro CT protocols. They report to the division or department head on implementation to ensure that protocols are based on evidence and need, and not on personal preferences. Thus, CT for persistent cough with routine chest protocol would be identical for all radiologists and would not vary based on days or radiologists or referring physicians.

CT radiographers have a pivotal role and distinction in the optimization process since they are the "troops on the ground" or the "musical instrument players," while radiologists and physicists play a role in composing the music and medical physicists act as the critiques or reviewers of the performance. The optimization of CT practice must be an auditable and documented process with logs and records of all activities. Therefore, one or more radiographers, based on their understanding of CT factors and techniques must be appointed as the "lead" or "supervising" CT radiographers who work with the Team on making and implementing CT protocols across the scanners and then, training their peers to ensure quality of service. With greater automation and artificial intelligence (AI), many scanners have become or are becoming automated, push- button machines, and such scanners will require little inputs or help from radiographers beyond contrast media injection. For example, some modern scanners can automatically look up at the indications, chose the right body region and protocol for scanning, center the patient, select the scan start and end location, place the region of interest for contrast bolus tracking or triggering, and automate image reconstruction and post-processing. Some scanners run AI actively looking for poor contrast enhancement or artifacts (metal- or motion- related) after scan acquisition. With the current and increasing automation, there is an expectation that CT radiographers would act as adjudicators of AI-led scan planning, scan data acquisition, reconstruction, image post-processing, medical records look-up (for checking indications for imaging, and contraindications to contrast media administration), auto-protocoling (determining the right protocol for each patient based on their history, physical exams, and prior imaging tests), detection of critical findings at the scanner graphic user interface (GUI), and radiology worklist prioritization (parsing exams that must be read sooner than others based on the presence of critical findings).

Medical physicists with expertise in diagnostic radiology also play a critical role in imaging chain optimization. Although diagnostic radiology-trained or focused medical physicists are scarce in many regions and countries, when available, they can provide meaningful inputs in protocol creation, radiation dose monitoring and optimization, as well as quality assurance. In-depth, hands-on experience in a clinical environment can substantially augment their familiarity with the clinical needs and requirements of CT protocols, specifically with the variations in doses based on different clinical indications and patient sizes. They must set up typical values of radiation doses and perform regular audits to identify exams with outliers (that is, exams with radiation doses well above the typical or notification levels), ideally with radiation dose monitoring software, but manually for sites without such software. For systemic issues, they must liaise with CT radiographers and radiologists to modify scan protocols that are not optimized from a dose or quality perspective. Medical physicists are also important in educating their colleagues on radiation doses and their impact. Furthermore, they also help determine and document fetal doses in pregnant patients undergoing radiation-based imaging tests (including CT or interventional radiology procedures).

***Table 2**. Roles and responsibilities of radiologists, CT radiographers & medical physicists*

Radiologists	CT Radiographers	Medical Physicists
• Need for CT protocols • Protocol naming • Clinical indications for triggering CT protocol • Intravenous and/or oral contrast media usage • Contrast volume and rate and injection rate • Scan phases (number and type – non-contrast, venous, delayed) • Scan start and end locations • Set desired quality • Reconstruction settings – thickness – kernels • Processing – MPR – MIP or MinIP • Have basic knowledge of scan factor & dose	• Protocol naming • Simplify indication to protocol triggering • Maintain protocol logs (dates, version, details) • Pre-save protocols on scanner GUI • Consult, chose correct protocol for right reason • Training on scan start and end location • Recognize issues with quality • Ensure low-dose scout • Ensure good centering • Bridge radiologist to physicist discussions • Apply right scan factors • Understand how scan factors influence dose • Understand basis of dose: CTDIvol & DLP	• Set local typical values • Teach radiographers on dose: CTDIvol and DLP • Monitor radiation doses periodically • Help troubleshoot quality issues • Audit dose alerts (high-dose exam) • Help select the right scan factors • Understand basis of clinical indications • Awareness of diagnostic reference levels • Maintain dose monitoring software • Assess centering, scan lengths, and phases for dose and quality outliers

5.2. REGIONS

The second TRIP item on the Region, or specifically, the regional anatomy of interest, has a profound impact on CT protocol and radiation doses. Here we discuss separate regions of the head, neck, chest, cardiovascular, and abdomen-pelvis to understand two things: one pertains to the anatomic peculiarities affecting the choice of CT scan factors and radiation doses and the other to underscore need to create body region-specific scan protocols.

Head: Starting from the head, when the brain is the anatomy of interest, supported by the densest bone in the body (petrous temporal bone) and challenged by the lowest contrast difference between the grey and white matter (8-10 HU), users must realize its unique implications on CT. To maximize image quality for the head versus the rest of the body, patients undergoing head CT need positioning in a special headrest to minimize artifacts and noise [83-86]. Noise has a disproportionately greater adverse effect on the visualization of organs and lesions with low contrast differences between its tissues or between its tissues and abnormalities. Dense bones leading to beam hardening (often seen as dark and/or bright bands in CT images) artifacts and low noise tolerance imply that the scanner uses a lower pitch (closer

to 0.5:1) and often slower gantry rotation values (often 0.8-1 second) for head CT. The scanners also employ special image reconstruction techniques and kernels to reduce beam hardening artifacts and noise. Thus, head CT protocols must not be built from a body CT protocol, and likewise, head-specific kernels or reconstruction algorithms must not be replaced with body CT kernels unless stated by the scanner vendor. Moreover, since the head size does not change much from the base to the vault, automatic exposure control (AEC) techniques do not offer a huge advantage over the fixed tube current method for dose optimization. Should the former techniques be the preferred method for head CT, image quality requirements for AEC must be set at a higher level (for example, higher quality reference mAs [Siemens], higher mAs/slice [Philips], lower noise index [GE], SD [standard deviation, Canon]) as compared to body CT. For example, a routine head CT is often scanned at 3-5 noise index versus a 10-15 noise index for abdomen CT and 20-30 for chest CT for the same slice thickness. Within the head CT, the intracranial vessels with high contrast from CT angiography can tolerate higher noise and require fast scanning time with lower image quality requirements from AEC, faster pitch, and faster gantry rotation time.

Regardless of the type of non-vascular clinical indications, most pediatric CT head exams must be performed without or with intravenous contrast media but not both. In adults and children, often head and neck CT angiography are performed with 2-3 scan phases.

Neck: The neck is a complex anatomic region with a smaller size in its upper portion and a highly attenuating and artifact-prone lower portion due to overlapping shoulders. Compared to the head, the variation in the size of the neck implies that AEC should be preferred over fixed tube current to maintain constant image quality and optimize the dose for neck exams. When performed without a chest CT in the same imaging session, the inferior landmark for neck CT is in the upper chest, frequently at the level of the aortic arch. The high inherent tissue contrast between the fat, muscles, airways, and blood vessels implies that neck CT can be performed at a lower dose than routine head CT.

There are a few notable caveats for neck CT exams. The first pertains to the breath-hold for non-airway-related abnormalities and free-breathing acquisition for the larynx. The second caveat pertains to the position of the arms when the neck is scanned with the chest in the same imaging session. A single-run CT through the neck and chest requires overhead arms by the side of the neck, which increases the radiation dose to the neck and causes artifacts and noise. Conversely, a dual-run neck and chest CT with separate scan acquisition through the neck and chest CT avoids the arms from the body region of interest and the ensuing artifacts and dose penalties. The latter increases the dose due to overlapping scan lengths between the neck and the chest CT. While neck and chest CT for blood vessels and airways and attenuation correction CT for PET/CT examinations are frequently single-run acquisitions. Conversely, most other soft tissue neck regions including thyroid, salivary glands, lymph nodes, and oro-pharyngo-laryngeal regions must be scanned with separate runs of neck and chest CT when performed in the same imaging session. Most neck CT examinations like chest CT regardless of clinical indication can and must be performed with single-phase CT protocols, either without or with intravenous contrast media.

Chest: Among all body regions, the chest is the most fertile ground for dose reduction in the body [87-90]. In general, the chest CT doses must be at least one-half of the abdomen CT doses for the same patient. There are several reasons why the chest must be treated with deference when it comes to dose reduction. First, air-filled lungs occupy most chest volume and cause little attenuation of the x-ray beam and noise, and therefore, allow scanning at lower dose CT with lower tube potential and tube current. Second, high inherent tissue contrast of lungs, blood

vessels, and the heart implies that abnormalities can be evaluated despite high image noise. Third, most chest CT examinations, regardless of clinical indications, need only one scan phase. There are infrequent exceptions to this rule, as discussed in the section on clinical indications. Fourth, within the chest, several chest indications can be imaged with several-fold lower radiation doses than other chest indications. Fifth, motion artifacts are frequent and can lead to repeat CT or compromised diagnostic information, and this requires faster acquisition times, such as with higher pitch (>1:1) and faster gantry rotation speed (< or = 0.5 seconds). Sixth, higher spatial resolution (thin reconstructed slice thickness at 1.25 mm or less) is important for lung and pulmonary arterial evaluations, but this does not require increasing radiation dose since lungs can tolerate higher image noise.

Since chest sizes vary with body habitus, AEC and automatic tube potential selection techniques must be used for most chest protocols regardless of clinical indications in pediatric and adult patients. The exception to this AEC rule is in patients undergoing very low-dose or ultra-low-dose CT protocols for lung cancer screening or lung nodule follow-up, which can be performed with weight-based, low fixed tube current instead of AEC.

Cardiovascular: Protocol optimization and technological breakthroughs have taken cardiovascular CT protocols from among the highest to some of the lowest dose exams [91-95]. This has been possible through scanners with higher temporal resolution, wide-area detector CT scanners, improved detector efficiency, and image reconstruction algorithms (iterative and AI-based reconstruction techniques).

Most cardiac CT exams can be performed with ECG-gated and prospectively triggered acquisition where the X-ray tube is turned off during certain phases of cardiac cycles, which are selected based on the patient's heart rate. Administration of beta blockers to slow the heart rate on some scanners can allow prospectively triggered cardiac CT or a narrower window of ECG-gate retrospectively acquired helical cardiac CT, both of which reduce doses substantially compared to fixed tube current. Next, due to the high contrast between the contrast-enhanced coronary and/or pulmonary vessels, automatic tube potential selection techniques can be applied to reduce doses and maximize contrast-to-noise ratio (CNR) with suitable adjustment to tube current with AEC. Modern scanners now enable cardiac CT examinations at 70-100 kV in both children and adult patients due to efficient detectors, high x-ray tube power, and lower noise images with iterative or AI-based reconstruction techniques. Since cardiac motion must be "frozen" for imaging, faster rotation times are critical for cardiac CT exams.

While cardiac CT exams have trended in the right direction from a radiation dose reduction perspective, powerful CT scanners can deliver much higher doses for multiphase vascular applications, specifically the thoracic and/or abdominal aorta or pre-transcatheter aortic valve replacement (TAVR). Indeed, users must carefully assess justification and scan factors for such multiphase exams in the era of scanners empowered by powerful X-ray tubes without tube heating constraints! Users must carefully examine the number of phases for the multiphase vascular CT exams to avoid high radiation doses. Fortunately, most patients undergoing vascular CT examinations tend to be older and sicker subjects, but younger and at-risk patients also undergo vascular protocol CT examinations.

Abdomen-pelvis: Like the brain, parenchymal lesions of solid abdominal organs have low inherent tissue contrast, such as the liver, spleen, and pancreas [96-99]. Therefore, their evaluation often requires higher doses than the corresponding chest of the same patient. Different abdominal abnormalities exhibit specific behaviors in different phases of contrast enhancement, which often helps detect and characterize these findings on multiphase

abdominal CT examinations. Multiphase CT exams involve scanning in multiple phases, such as non-contrast, arterial, portal venous, and delayed phases. If all scan factors and lengths are kept constant across different phases, radiation doses multiply and increase substantially compared to single-phase CT examinations. Compared to other body parts, where each phase images the entire anatomy in different phases, such as in the brain and neck, in the abdomen, it is possible to limit the coverage for one or more phases to a single organ or lesion of interest instead of scanning the entire abdomen to reduce radiation doses for multiphase CT examinations. Like chest CT, abdomen CT must be performed with AEC and automatic tube potential selection techniques, and when available, mild to moderate strength of iterative reconstruction must be used to help improve image quality.

Since motion artifacts are less concerning in the mid to lower abdomen, usually a smaller pitch (< or = 1:1) and slower rotation time are used for abdomen CT, particularly on older scanners with limited x-ray tube power and in overweight or obese patients.

5.3. INDICATIONS

The third item of the TRIP strategy is perhaps the most important part of justification and optimization –Indications for ordering or requesting CT examinations. The availability of ***correct*** and ***complete*** clinical indications is an important aspect of protocol creation and radiation dose optimization. In typical imaging workflow, radiologists and/or CT radiographers must check and link clinical indications to appropriate clinical indication-based protocol. With the growing applications of AI in medical imaging and the emerging literature, it is anticipated that linking clinical indications to CT protocols and scan factor selection will be automated using either a rules-based approach and/or large language models (LLMs) [104]. Such software could also check clinical indications from medical records, history or documentation of contrast reactions, and description of any artifacts such as motion or metal-related in prior radiology reports to recommend and/or modify scan factors at the time of CT scanning.

Personalization or creation of clinical indications-based CT protocols does not require creating several dozen protocols. The purpose of such endeavors is to group multiple different clinical indications to specific CT protocols based on the similarities in their scanning approach governed by their body region and type of organ/lesion under evaluation. Such grouping allows low-dose protocols for specific clinical indications unaffected by high image noise, such as pre-endoscopy CT for sinus surgery, lung nodule follow-up, lung cancer screening, kidney stones, and ventricular shunt patency. Such grouping also allows users to limit the multiphase, higher-dose CT protocols to specific and limited clinical indications. For example, detection and characterization of parathyroid lesions in the neck; diffuse lung diseases and tracheal collapsibility in the chest; and liver, pancreatic, adrenal, and renal lesion evaluation in the abdomen. Most clinical indications are clubbed in for a baseline or routine protocol, often with a single-phase CT protocol.

Table X3 summarizes routine, non-routine, and special clinical indications for head, chest, and abdomen-pelvis CT. Routine clinical indications usually require only a single-phase CT examination with or without intravenous contrast. These must constitute the most common CT protocols regardless of the practice settings. The non-routine clinical indications require a special protocol (such as a CT pulmonary angiogram with a single-phase CT) or more than one CT phase with and without intravenous contrast injection. The special clinical indications are those where single-phase CT examinations are performed at lower radiation doses than the other

routine and non-routine indications. All departments must have at least three CT protocols to include these separate groups to personalize radiation dose and scan techniques to clinical indications.

Table 3. *Routine, non-routine, and special clinical indications for head, chest, and abdomen-pelvis CT*

	Frequent head CT indications	Common chest CT indications	Usual abdomen-pelvis CT indications
Routine	Head injury Stroke (ischemic or hemorrhagic) Intracranial hemorrhage Headache Suspected infection Suspected metastases Surgical/intervention complication	Persistent cough Cancer staging Hemoptysis Chest trauma Suspected pneumonia Cancer – treatment response	Abdominal pain Hypo-vascular cancer staging Altered bowel habits Weight loss Suspected infection Diverticulitis
Non-routine	Ischemic stroke (CTA+/- perfusion) Suspected or known aneurysm Suspected or known AVM Venous sinus thrombosis	Suspected emboli Pulmonary fibrosis Tracheal stenosis Tracheomalacia	Liver lesion evaluation Pancreatic cancer Renal lesion evaluation Adrenal lesion Hyper-vascular cancer staging
Special	VP shunt patency Craniostenosis Pre-endoscopic paranasal surgery	Lung nodule/s follow up Lung cancer screening Pectus excavatum	Urinary colic or stones Appendicitis CT colonography (screening or diagnostic)

Correct and complete clinical indications do not imply long notes or the entire clinical notes and physical examinations. The ongoing research suggests that future and current scanners and decision-support systems can “auto” link clinical indications to scan protocols; however, such linking capabilities also require succinct information. Herein lies the need for raising awareness among the referrers or requesters of imaging tests to understand the benefits of justified imaging

and imaging tailored to answer specific questions where information is maximized, and radiation risks are minimized. Some clinical indications, such as the ones summarized in Table X4, must result in automatic re-request for clarification before scheduling or performing imaging.

Table 4. *Incorrect and incomplete clinical indications should trigger a re-request for adequate information or rejection of imaging requisition.*

Indication Type	**Clinical indications**
Incorrect	Cancer staging Abnormal imaging As per radiologist Outside physician or referrer Call xxx-xxx-xxxx (phone) for information/indication Clinical information not available Patient insists/requests imaging Cough (Order – abdomen CT) Schizophrenia (Order - abdomen CT) All indications not suspected or present in the patient
Incomplete	Abnormal imaging (State the finding and imaging done) Elevated biomarkers (State the biomarker/cancer) Cancer staging (state the primary or say occult if not known) Suboptimal imaging (state reason for suboptimality) Follow-up (state the specific finding for follow-up) Treatment response (state the treatment and disease) Cancer screening (state which cancer if known) Abdominal pain (state specific location, type or suspicion) Persistent cough (state whether radiograph was done)

* The text in parenthesis summarizes the remedial steps for obtaining complete clinical information

5.4. PROTOCOLS

The fourth step in the TRIP strategy involves a Team incorporating the nuances of body regions and clinical information to create scanner-specific CT Protocols. Scanner-specific CT protocols have three purposes: 1. Best use of scanner strengths and technologies to create appropriate protocols. Such as automatic tube potential selection and iterative or AI-based reconstruction techniques in the protocols. 2. Harmonize scan phases and scan lengths for common protocols. 3. Harmonize image reconstruction and processing tasks so that common scan protocols provide comparable studies across multi-scanner sites.

Each site must have separate protocols for adults and pediatric patients and different body regions such as the head, neck, chest, abdomen-pelvis, and heart. Next, each named protocol must specify the body region, clinical indications, scanner vendor and name, and the version date for creating the protocol. The sites should review and update the protocol at least annually.

Table X5 summarizes key elements of scan protocols. Note that a single CT protocol can have multiple clinical indications, such as those summarized in different groups in Table X3. It is important to note the version-date so that the protocol updates can be recorded in a formal manner. The administration of oral and intravenous contrast impacts the choice of scan factors and radiation dose, and, therefore, their details must be included in the scan protocol details.

Planning radiographs (aka scout/surview/topogram) affects the choice of tube current and potential, and the protocol must specify single or orthogonal views and the applied kV/mA. Radiographers must center the patient in the gantry isocenter before the acquisition of planning radiographs since off-centering affects the estimation of patient size and attenuation, which, in turn, impacts the functionalities of automatic exposure control and automatic tube current selection techniques. When off-centering is present on the radiograph, radiographers should re-center the patient and reacquire the radiograph. Moving the reconstruction field of view to center the images does not change the incorrect estimation of lower or higher radiation dose.

5.4.1. Proper positioning and scan ranges

Centering and the patient: Patient centering is important for image quality and radiation dose optimization. The following figures illustrate the correct positioning and scan ranges for a given body region, as well as the most common types of mistakes.

5.4.2. Head examinations

A single scout (lateral) is typically sufficient for planning the scan start and end location (scan coverage or volume). Two scouts can help prescribe the scan volume with better accuracy in patients with less than adequate positioning. Note that a head CT does not include the cervical spine and face, which need separate acquisition (unless the neck is part of a CT angiogram acquisition). Typically, orbits, paranasal sinuses and cervical spine can be scanned at much lower CTDIvol as compared to the brain. Also, the scan coverage for head CT extends from the skull base/C1 to the vertex.

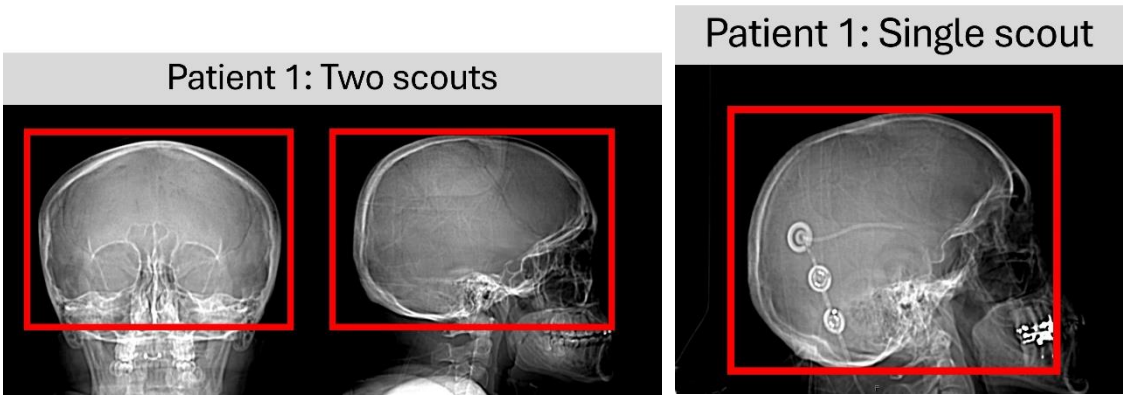

Figure 2 *Head CT: A single scout (lateral) is typically sufficient for planning the scan start and end location*

Fig 3 shows that the green circle (scanner isocenter) does not match with the patient isocenter. Most commonly, users just move the planning box (red) to align the patient and scanner isocenter (Fig 3B). This is WRONG. Instead, one should always move the patient table to get the two centers aligned (as in Fig 3C) and then change the dimensions for reconstruction (as in Fig 3D).

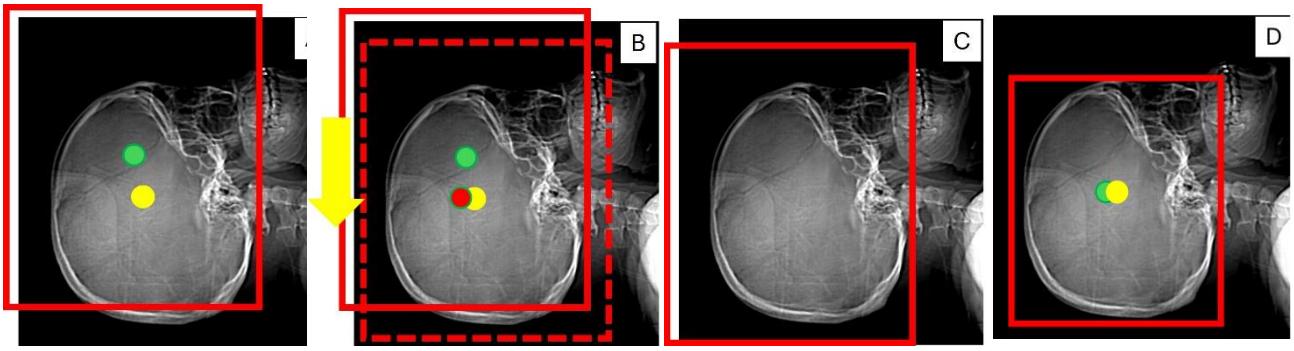

Figure 3 *Patient cantering and scan range in head examination*

5.4.3. Chest examinations

The top-row scouts did not get the lung bases, so dose modulation will not work beyond the scout edge. ECG leads overlying the chest must not be bunched or coiled together to avoid artifacts in CT images.

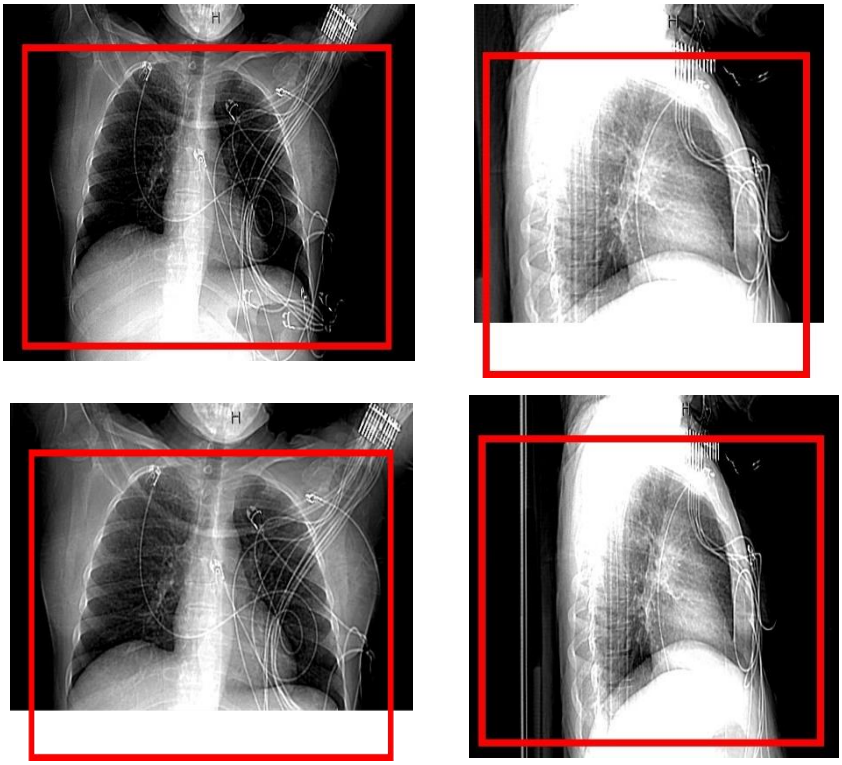

Figure 4 *Two pairs of frontal and lateral of scouts from the same patient*

For post-contrast chest CT, the coverage extends from the lung apex to the adrenals. The inferior coverage is to lung bases only for non-contrast CT for incidental nodules and lung cancer screening. There are two main issues with these scouts. The top-row scouts did not get the lung bases, so dose modulation will not work beyond the scout edge. ECG leads overlying the chest must not be bunched or coiled together to avoid artifacts in CT images.

Three protocols of chest CT: All with single-phase acquisition, like most chest CT exams

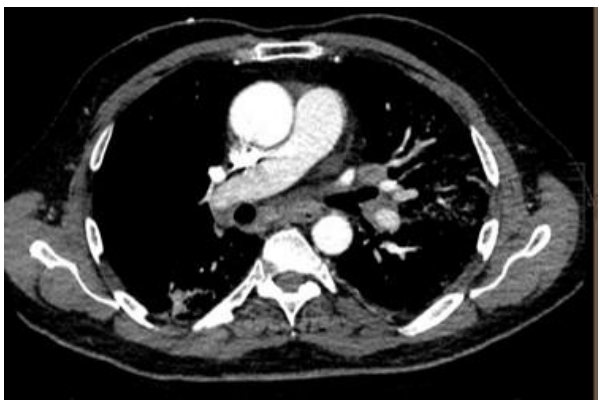

Figure 5 ***Single-phase, post-contrast chest CT*** *demonstrates hilar lymph nodes with incompletely assessed pulmonary opacities on the soft tissue window. CTDIvol= 9 mGy (weight 80kg)*

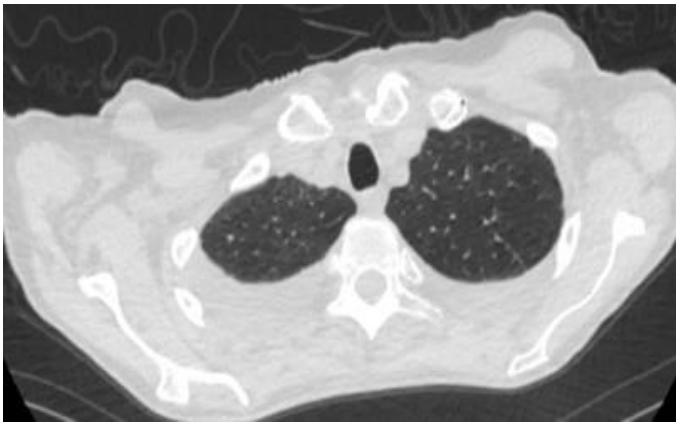

Figure 6 Single-phase, non-contrast chest CT *with low-dose lung nodule follow-up protocol shows a tiny right apical nodule and right pleural effusion. CTDIvol = 3 mGy (weight 78 kg)*

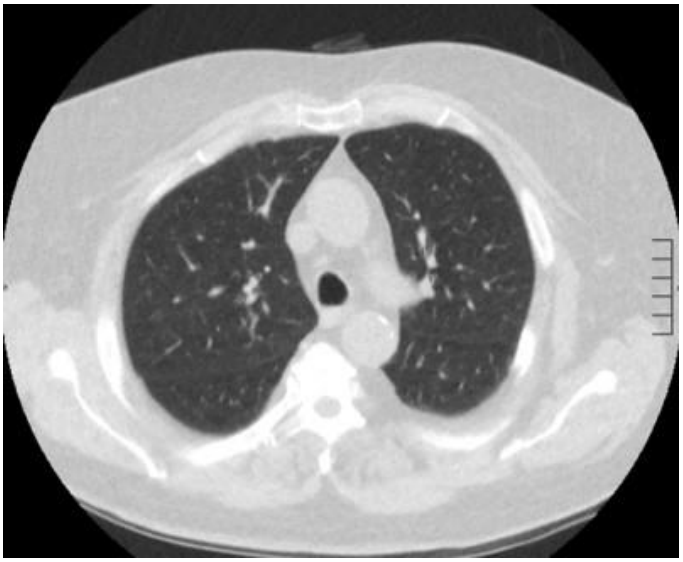

Figure 7 Single-phase, non-contrast chest CT *with low-dose lung cancer screening protocol does not demonstrate any abnormality. CTDIvol=1.2 mGy (weight 96 kg)*

5.4.4. Abdominal examinations

Routine abdomen-pelvis CT

The scan volume extends from just above the diaphragm to the pubic symphysis. It is a single-phase CT (with OR without contrast). Delays (green box) are only acquired after a review of the initial phase, over the abnormality region, and NOT over the entire abdomen-pelvis.

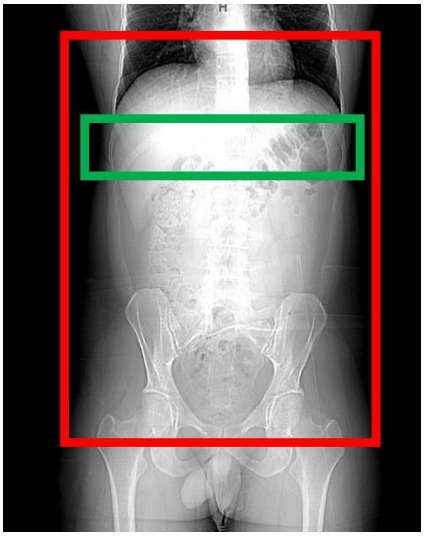

Figure 8 *Routine abdomen-pelvis CT scan range in a single phase (red) and delays phase (green)*

Kidney stone CT

The scan volume extends from the top of the kidneys to the pubic symphysis. Note that kidney stone CT protocol is not a non-contrast routine abdomen-pelvis CT. It is a low-dose, single-phase CT protocol.

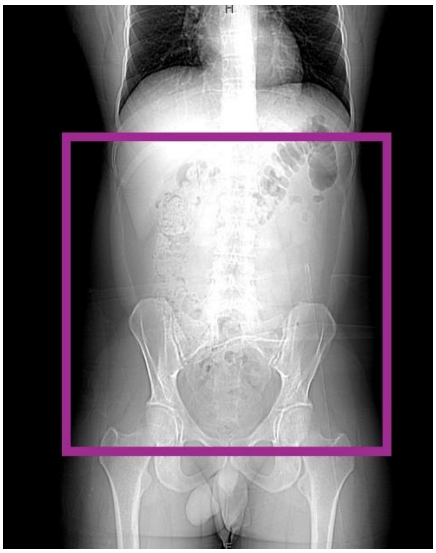

Figure 9 *Kidney stone scan range*

Non-contrast single-phase, low-dose kidney stone CT protocol

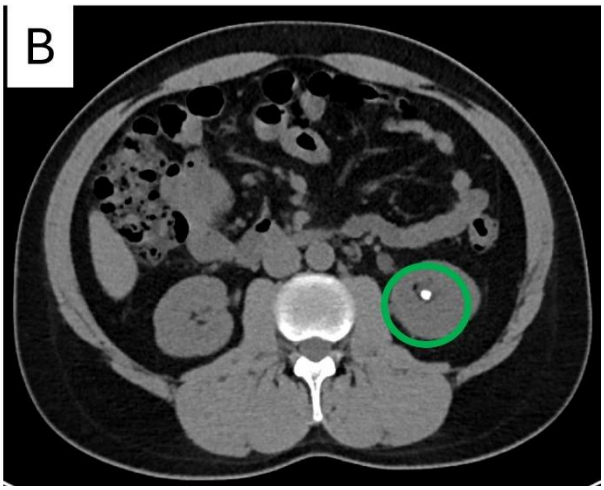

Figure 10 *non-contrast single-phase, low-dose kidney stone CT protocol shows the left renal stone with the excellent image quality of a photon-counting detector CT at a lower dose (CTDI 3.5 mGy; weight 75 kg).*

Liver protocol CT

This should be referred to biphasic liver. The first arterial phase (blue) is usually only through the liver or upper abdomen. The second portal venous phase is through the entire abdomen-pelvis (orange). The green, delayed phase is optional and through the lesion or the liver only. Note that there is no non-contrast phase.

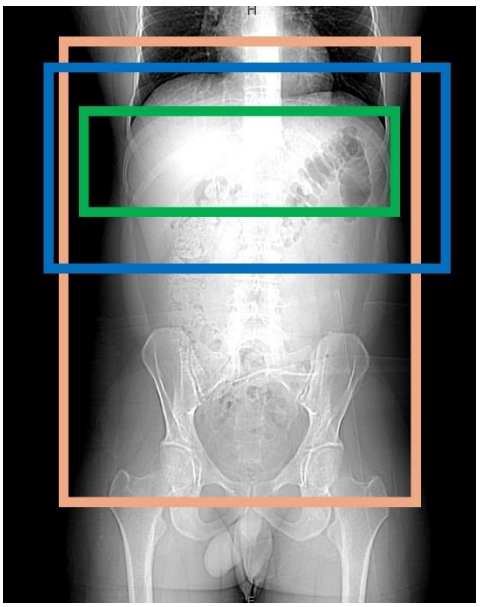

Figure 11 *Liver scan range in the arterial (blue), portal venous (orange) and delayed phase (green)*

Biphasic liver protocol

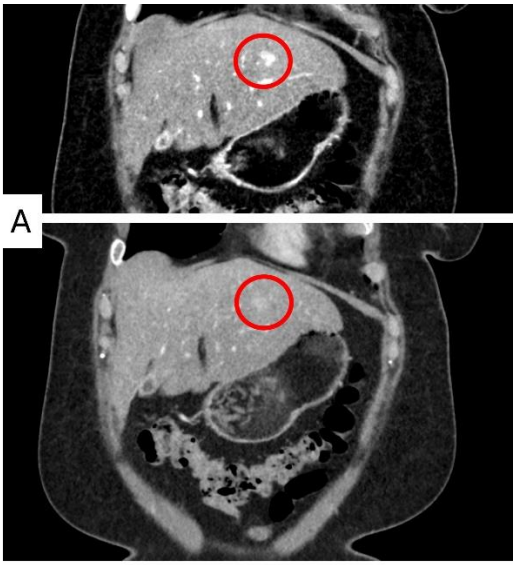

Figure 12 *Biphasic liver protocol CT with arterial phase (liver only) and portal venous phase (abdomen-pelvis coverage) demonstrate enhancing lesion in the left hepatic lobe. Energy-integrating detector CT with CTDIvol for both phases 14 mGy; weight 85 kg.*

Triple-phase pancreatic cancer protocol CT

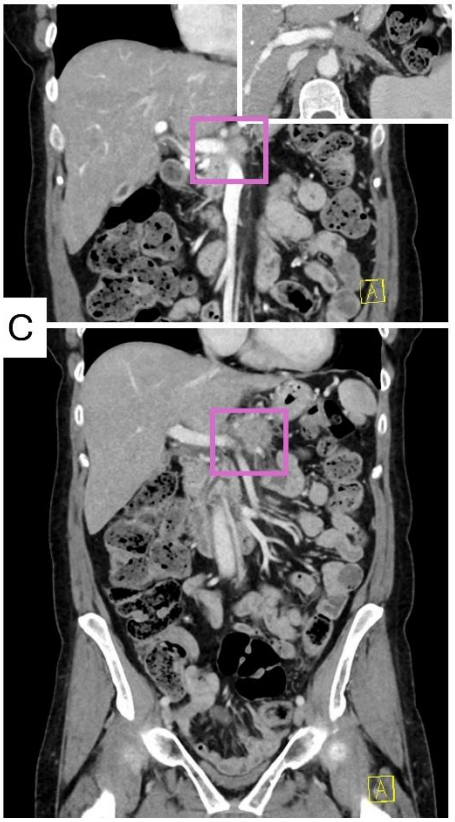

Figure 13 *triple-phase pancreatic cancer protocol CT (two phases presented) demonstrates pancreatic cancer. Note the upper abdomen coverage of the arterial phase and whole abdomen-pelvis for portal venous images (CTDIvol, both phases= 9 mGy; DLP (arterial) 269 mGy.cm; DLP (portal) 428 mGy.cm; weight 81 kg)*

Adrenal protocol CT

Usually, for a nodule seen on prior chest and/or routine abdomen CT. This is a three-phase protocol with non-contrast, portal venous, and 15-minute delayed phase CT with identical scan volume from T11 to L2 vertebrae.

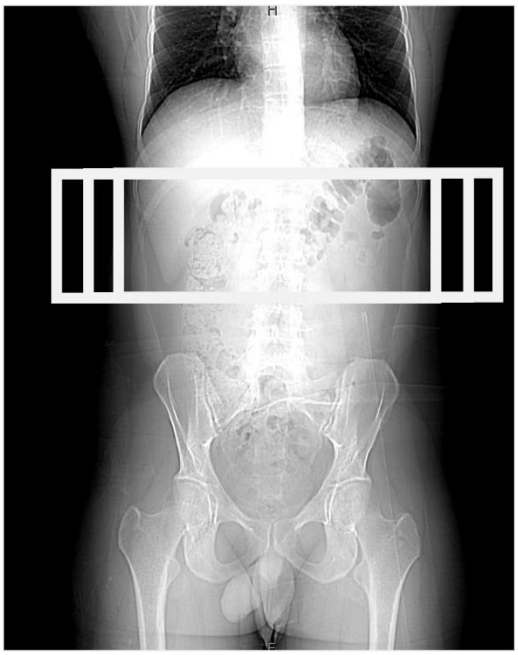

Figure 14 *Adrenal protocol scan range*

5.5. BUILDING PROTOCOLS AT DEPARTMENTAL LEVEL

Table 5. *Key elements of scan protocols.*

CT (body region) (protocol name) (without and/or with contrast)				
Scanner vendor & name:	Version date: (MM/YYYY)			
Clinical indications for use				
Oral Contrast Yes/No Volume Time before scanning				
Intravenous contrast use	Yes/No			
Intravenous contrast Rate, volume, concentration (xxx mg%)		Volume	Injection rate	
	Contrast			
	Saline			
Scan delay from contrast injection	Bolus tracking/test bolus/ fixed delay			
Surview/Scout/topogram Single or double Body region kV/mA				
Number of scan phases	1/2/3/4/more			
PLEASE provide items below for each scan phase (limit scan location repetition) *Scan phase 1*				
Scan phase name	Non-contrast/arterial/venous/delayed phase			
Scan phase start location				
Scan phase end location				
Tube current (Fixed)				
AEC	Name	IQ parameter	Min-Max mA	
Tube potential	Fixed/reference kV		Preset**	
Pitch				
Detector geometry	# detector rows * width mm			
Gantry rotation time (second)				
Reconstruction	Technique	Name	Strength	
	FBP/IRT/AI			
Prospective (1st) slice	Thickness	Interval	Kernel/filter/algorithm	
	mm	mm		
Retrospective slices	Thickness	Interval	Kernel/filter/algorithm	
	mm	mm		
Reformats/post-processing	MPR/MIP	Plane	Thickness	Interval
	Ax/Sg/Cr		mm	mm

** MPR multiplanar reformats; MIP maximum intensity projection; Ax/Sg/Cr axial/coronal/sagittal; Preset** refers to the setting or station for automatic tube potential selection technique such as non-contrast, routine abdomen, and CT angiography*

Table 6 details the rules for scan phases, which refers to the number of times a patient is scanned (not including the planning radiographs and test/timing bolus images). There are five ways to optimize CT protocols and radiation doses with scan phases: 1. Avoid unnecessary multiphase CT (most routine chest and abdomen CT protocol must have one phase); 2. Reduce the use of multiphase CT for some follow-up CT (such as CT angiography for thoracic and/or abdominal aorta); 3. Limit scan coverage for one or more phases (such as limit coverage of arterial and delayed phase acquisitions to the liver for multiphase liver protocol); 4. Reduce radiation dose (with other scan factors such as with lower kV and/or mA). 5. Tie specific and limited clinical indications for the use of multiphase CT protocols.

Table 6. *Summary of scan phases for common CT protocols*

Protocol	**Non-contrast**	**Arterial**	**Venous**	**Delayed**
Routine– Chest	OR	OR	_	-
CT PA	_	+	_	_
Diffuse lung ds	1 or 2 phases (Inspiration &/or Expiration)	OR	_	_
Tracheal protocol	(Inspiration & Expiration)	_	_	_
Lung nodule/screening	+	_	_	_
Routine – abdomen	OR	_	OR	_
Biphasic liver	_	+ (liver)	+ (abdomen)	OR
Hematuria	+	_	_	Split bolus phase
Kidney stones	+	_	_	_

** key: - not required; + required phase; OR - for two-phase protocol implies that only one of the two phases is needed*

***for example, for routine chest or abdomen, only one phase is sufficient without or with contrast media; split bolus represents injecting IV contrast in two phases to reduce radiation dose rather than acquiring two scan phases*

Users can cleverly use scan length to optimize CT protocol and radiation doses. Scan protocols must define the anatomic landmarks for scan start and stop locations. Recent innovations in AI technologies with scanner-mounted 3D cameras can now automatically determine and plan the scan length based on the prescribed CT protocol. When all other scan factors are kept constant, longer scan length translates to higher radiation dose. An inadvertently or unnecessarily long

scan length also increases the number of images, radiologists' workload, image upload and display times, and reduces the selection of lower tube potential, specifically for older scanners. While routine chest (lung apices to adrenals) and abdomen-pelvis (top of the liver to pubic symphysis) CT protocols will cover the entire anatomic region, the non-routine and multiphase CT protocols can vary scan length to reduce radiation doses. For example, CT pulmonary angiogram, lung nodule follow-up, and lung cancer screening only extend to the lung bases without extending up to the adrenal glands. Likewise, a shorter scan length may be adequate, limited to the organ or lesion of interest, for some phases, such as the non-contrast, arterial, and delayed images. When non-contiguous scans are performed in the same imaging session for multiple continuous body parts (such as chest and abdomen-pelvis), overlapping scan lengths must be minimized over the junction regions between the two body parts.

Table 7. *Scan factors, their preferred settings and impact on radiation doses.*

Scan Factors	**Preferred setting**	**Impact on dose**
Planning radiograph (scout/topogram)	**Center** patient prior to acquisition Repeat if centering correction needed	**Extremely** low dose **Helps** plan scan range **Important** for AEC
Tube current (mA)	**Use** AEC for most CT exams **Change** the IQ parameter based on clinical need **Requires** good centering	**Linear** relation with dose **Adjusts** mA per body size/attenuation **Some** AECs have complex relation to slice thickness and pitch
Tube potential (kV)	**Use** automatic kV selection **Otherwise**, weight-based selection **Low kV** (≤100) preferred for pediatric CT, post-contrast CT (non-obese), chest CT	**Profound** effect on dose **Dose** varies by the square of the kV change
Gantry rotation time	0.5-1sec- head CT 0.5-0.8sec- most neck-chest-abdomen <0.4 sec- cardiac CT/motion-sensitive CT	**Linear** relation with dose **Slower** speed for morbidly obese abdomen-pelvis CT
Pitch	~ 0.5:1 - head CT 1-1.5:1 - most neck-chest-abdomen <0.4:1 - retrospective ECG cardiac CT	**Adjust** for speed not dose **Some** CT, higher dose at low pitch **Some** CT, no dose effect of pitch
Detector configuration	Selection based on clinical requirements ≤64-slice CT- variable detector width > 64-slice CT – equal detector width	**Wider collimation** dose efficient for long scan range; Narrow collimation better for head and short scan range

Table 8. Reconstruction factors and their preferred settings and impact on radiation doses.

Reconstruction factors	**Preferred setting**	**Impact on dose**
Slice thickness	**Must** be selected based on body region and need for spatial resolution **Rising** trend towards thin sections (≤ 1mm)	**On some CT** (GE, Canon), slice thickness can change dose due to higher noise in thin slices.
Kernel/algorithm/ filter	**Depends** on body region. **Head & chest** – soft and sharp (lungs/bones) **Abdomen-pelvis** – soft	**No impact** on dose **Too sharp** kernel can increase noise and force user to increase dose.
FBP reconstruction	**On most** older scanners. **Higher noise** at lower dose, more artifacts **Good/familiar** image texture or appearance	**Higher noise** implies less potential for reduced radiation dose scanning. Limited low-dose CT beyond lungs
Iterative reconstruction (IR)	**On most** new scanners. Current **gold and preferred standard** **Much improvement** in image appearance Chose mild/moderate strength initially	**Lower noise** & artifacts = opportunities for low dose CT beyond lungs **Enable** ultra-low-dose CT for lungs
Deep learning reconstruction	**On newest** scanners **Emerging technique** with better image look **Few presets** for strength of denoising	**Only** small studies proving dose benefits over IR. **Combined** with IR/FBP.

Tube current is the most frequently adjusted factor for protocol and dose optimization among scan factors due to its linear relationship with image noise and radiation dose. Most CT examinations must be performed with automatic exposure control or automatic tube current modulation techniques (or automatic exposure control – AEC) rather than a manually selected fixed tube current. The AEC techniques require users to specify an image quality parameter based on the diagnostic quality need for specified CT protocol or clinical indication. The scanner then adapts the tube current around the patient as the x-ray tube rotates around the patient (angular AEC) or along the patient (as the table slides in or out of the gantry along the patient length (longitudinal AEC) or both (combined or xyz- AEC). Thus, users must adapt the image quality parameters based on the desired quality rather than patient size. Bunching up several clinical indications to CT protocols enables users to customize the AEC image quality parameters and enable dose adjustment based on the diagnostic need. When using AEC, radiographers must strictly adhere to the following aspects of scanning:

1. The planning radiograph (scout or topogram) must cover the intended scan start and end location.

2. Most vendors only use the last planning radiograph of AEC. Be aware of your scanner specifications. Do not hesitate to ask the vendor for details.

3. Patients must be centered in the scanner gantry isocenter (the patient center must coincide with the center of the gantry aperture). Otherwise, the planning radiograph cannot reliably estimate patient size/attenuation, and there can be over- or under-estimation of tube current.

4. Be aware of the limitations of AEC in very small (little children) or large patients (morbidly obese).

5. Be aware that some AEC doses are affected by the prospective slice thickness (slice thickness of first scan series)

6. AEC adapts tube current automatically to changes in other scan factors such as tube potential, gantry rotation speed, and pitch.

7. Incorrect image quality parameters can increase radiation dose beyond the level needed for diagnostic-quality images.

The automatic tube potential selection technique (ATPS) also uses a principle similar to AEC. Based on the user-specified exam or scan phase type (such as non-contrast, routine post-contrast, and CT angiography), the scanner examines the patient size and other scan factors (tube current capacity, gantry rotation speed, pitch, and scan length) to select the best tube potential (one kV value per acquisition) to retain a constant contrast to noise ratio. Thus, for smaller patients undergoing CT angiography, ATPS will use lower kV than for a non-contrast CT in the same size patients and for larger patients undergoing CT angiography. Newer scanners with high tube current limits will enable the choice of lower kV (such as 60-80 kV); there is a larger kV choice on such scanners (from 5-9 kV settings between 60 – 150 kV).

On the CT scanners without ATPS, the users must specify protocol and/or size-based tube potential for scanning. For such scanners, a general rule to follow is that non-obese chest CT and most pediatric CT (up to 70-80 kg) can be scanned at less than or equal to 100 kV. When available, iterative and/or deep learning-based reconstruction techniques must be used to decrease noise and/or artifacts. Proper tube potential use helps reduce radiation dose and improve lesion detection and evaluation on post-contrast CT.

Gantry rotation speed and pitch are often used to adjust scan duration rather than radiation doses. Most but not all scanners modify tube current to keep relatively constant radiation doses regardless of the scan duration. There are, however, exceptions, such as for some GE and Canon scanners, where a lower pitch is associated with a slightly higher dose and a higher pitch with a lower dose. Other scanners increase the tube current with a higher pitch to keep a constant radiation output. Faster scan time is important for pediatric and cardiovascular applications and patients who cannot hold still or perform a breath-hold.

The choice of detector configuration again depends on the spatial resolution demands and scan length. A narrow detector width reduces over-ranging for shorter scan lengths (such as for head and paranasal sinus CT protocols) and better adapts to changing anatomic structures within the region of interest, A wider detector configuration is more dose efficient for a longer scan length (such as chest, abdomen CT or chest-abdomen-pelvis CT).

Table y summarizes reconstruction factors and their impact on radiation dose. In addition, the users must familiarize themselves with typical values, diagnostic reference levels (DRLs), and achievable doses (ADs). These are important tools to help optimize, monitor and benchmark radiation doses. The DRLs and ADs refer to the 75^{th} (third quartile) and 50^{th} (median) percentile of dose distribution (CTDIvol and DLP) across multiple CT examinations and sites. Various national and international studies have published data and recommendations on DRLs based on specific patient groups (adult and pediatric patients), imaging modalities (such as radiography and CT), body regions (such as head, chest, and abdomen CT), and clinical indications or

protocols (such as routine chest CT, CT pulmonary angiogram, routine head CT, liver protocol CT).

While DRLs and ADs help compare radiation doses on regional, national, and international levels, typical values help monitor local doses in the context of local patients, scanning equipment, and protocols. While local DRLs can be estimated from a sample of 20-30 imaging procedures per body region and/or per protocol, at the third quartile values, the typical values represent the median value of dose distribution. For newer equipment, typical values should be lower than the local or national DRLs. Radiation dose monitoring software can help automate the establishment of typical values and local DRLs, and these levels can be used to set local alert values. A multidisciplinary team of radiographers and physicists is important to investigate CT protocols and exams that exceed the alert values. All DRLs and typical values must be revisited at least once every 2-3 years.

6. EDGE CASES FOR CT

6.1. PEDIATRIC PATIENTS

Children are special and must be treated with special care in CT due to their smaller body size, different clinical reasons for imaging, and higher potential radiation risk relative to adult patients. As for adult patients, always consider the justification of CT in children. For most indications not related to head injury or acute neurologic emergencies, consider MRI. Many non-emergent and some emergent abdominal clinical indications in children can be imaged with ultrasound (such as renal colic, appendicitis, and other abdominal pain) or MRI.

Once the decision is made to proceed with the CT for smaller children, users must carefully consider using a higher-end, faster CT scanner or anesthesia/sedation to minimize motion artifacts and repeat scanning [100-103]. Never use the adult protocols for children under 15-16 years of age or older if they are smaller than an average adult patient. Always make CT protocols that are indication-wise (dose varies based on clinical indications) and child-size adaptable (lower dose for smaller children).

When necessary, pediatric head CT should be performed without or with intravenous contrast media. The same rule applies to chest CT, whether in children or in adults. Most chest CT exams in children and adults can be and should be performed at 70-100 kV and with at least one-half lower dose compared to abdomen CT. When performing abdomen-pelvis CT in children, minimize multiphase CT exams by eliminating routine non-contrast and delayed phases and reducing scan coverage/lengths for other phases to the regions of interest. For multiphase CT, arterial phase acquisition can be at lower kV than the portal venous phase of contrast enhancement.

6.2. OBESE PATIENTS

On the opposite spectrum of pediatric patients are obese adult patients, who represent a substantial portion of the population undergoing imaging studies. While AEC and ATPS, especially when coupled with iterative and/or deep learning image reconstruction, can provide

acceptable image quality on the scanners equipped with these technologies, there are some caveats that users must remember:

1. Combination of obesity and multi-phase CT protocols are associated with extremely high radiation doses: Use proper clinical judgement on the use and techniques of multiphase CT. Minimize the number of scan phases and scan coverage where possible. For example, liver protocol CT can be performed without non-contrast phase, with arterial and delayed phase coverage limited to liver only, and portal venous images spanning the entire abdomen-pelvis. Likewise, the use of single-phase CT for neck and chest CT examinations.

2. Newer scanners with powerful single- or dual-x-ray sources can deliver extremely high radiation doses in obese patients. While high radiation dose is necessary to obtain sufficient diagnostic quality for some clinical indications, in other patients extremely high radiation doses are not necessary (such as for chest CT).

3. Absorbed radiation dose is related to the volume of irradiated cross-section. The 32-cm plastic phantom used for estimating CTDIvol and DLP substantially overestimate overall radiation doses to obese patients. While CTDIvol represents the average absorbed radiation dose, the dose length product refers to the total radiation dose over the entire scan length (series DLP – over individual scan acquisition, total DLP – over the entire exam with addition to doses from different acquisitions). The CTDIvol and DLP are phantom doses (dose estimates from 32 cm phantom size for all body CT exams and 16 cm phantom size for head CT) and not patient doses. These dose metrics allow comparison of radiation doses across different scanners and protocols. From risk perspective, chest and abdominal wall fat is relatively radiosensitive and absorb most low energy x-ray photons thus reducing radiation dose to internal, more vulnerable organs.

4. On the older scanners, without powerful x-ray tubes or reconstruction techniques, users must modify scan factors to obtain diagnostic quality at higher radiation doses. This can be accomplished with the use of higher tube potential, higher tube current, slower gantry rotation speed (0.8-1 second), and smaller pitch (<1:1). Image reconstruction with softer algorithms, filters, or kernels (lower spatial frequency) can help reduce image noise as can higher strength of iterative reconstruction technique. For example, with the use of 4/5 strength for iDose (Philips), 50-60% ASIR/ASIRv (GE), and 3/4 Safire/Admire/QIR (Siemens).

6.3. PREGNANT PATIENTS

Like children, pregnant patients also warrant special consideration for CT. From the justification perspective, there are four things to consider in pregnant patients:

1. Is there a justifiable clinical indication for performing CT? There must be a compelling clinical reason for CT, just as in any patient.

2. Can the justifiable clinical indication be safely postponed until after pregnancy?

3. Can non-ionizing radiation-based imaging tests (ultrasound or MR) provide similar information? For example, patients with suspected pulmonary embolism first undergo

a Doppler ultrasound to evaluate deep vein thrombosis (DVT) in the lower legs and have CT if the ultrasound is negative or inconclusive. Likewise, ultrasound is the first-line imaging test for suspected appendicitis in children and pregnant patients. A positive test prevents further testing. An inconclusive result triggers an MRI to evaluate the appendix. CT is reserved for patients with inconclusive MRI.

4. Is the clinical indication amenable to a single-phase CT protocol? Most chest indications should be performed with a single-phase CT protocol with or without contrast, as in non-pregnant patients. Abdominal-pelvis CT results in direct exposure to the conceptus, and therefore, radiation dose must be optimized with careful selection of scan phases. A single-phase abdominal CT with intravenous contrast (inflammatory or neoplastic diseases) or without contrast (kidney stones) is sufficient for most patients.

From an optimization point of view, CT in pregnant patients has the following considerations:

1. Head CT: No modifications are required since there is little to no scattered or direct radiation to the conceptus. The use of a lead apron or shield over the abdomen of a pregnant patient undergoing a head and/or neck CT is not necessary since there is negligible external scattering of radiation, and the apron or shield cannot protect the conceptus from internal scattered radiation.

2. Chest CT: Due to hyperdynamic circulation, contrast enhancement can be suboptimal in 10-30% of pregnant patients, particularly for evaluating pulmonary embolism. Bolus tracking or test bolus, breath-hold suspension (instead of breath-hold after deep inspiration), and lower tube potential (<120 kV) can help reduce suboptimal contrast enhancement. The use of lead shield or apron is again of little use for chest CT and must be discouraged. Likewise, the administration of barium for chest CT is also not helpful and may increase image artifacts and/or radiation dose when used in combination of AEC/ATPS [105]. Instead, the focus should be on limiting the scan coverage to the chest only, and avoiding extension of scan length to cover the adrenal glands.

Abdomen-pelvis CT: Limiting the number of scan phases is the most important aspect of dose optimization for abdomen-pelvis CT. AEC and ATPS must ensure that diagnostic-quality images are obtained with a size-based adjustment in the applied tube current and potential. Although AEC can choose a higher tube current in later pregnancy, obtaining images of sufficient diagnostic quality is important.

7. REPETITIVE SCANNING

In recent years, there have been concerns over cumulative radiation doses from repetitive scanning for both oncologic and non-oncologic patients. There is a worldwide rising reliance on imaging for assessing disease extent, stage, severity, surveillance, and recurrence; treatment guidance, response assessment, and toxicity; predicting patient outcome. While these uses are a testament to tremendous imaging technological advances and availability worldwide, the increasing use, and at times, with doubtful or clearly redundant value, increases healthcare costs, patient anxiety, and radiation risks without measurable benefits. To compare imaging findings across baseline and follow-up imaging tests, there is a need for consistent CT protocols and acquisition techniques, which makes it challenging to implement dose reduction for follow-

up CT exams versus the initial exams. Hence, the initial CT protocols must be optimized so that excess and unnecessary practices and their impact do not propagate onto subsequent imaging exams. It is important to follow evidence-based guidelines for follow-up and disease surveillance to avoid unnecessary imaging tests.

Regardless of origin, most malignancies do not require non-contrast CT before the post-contrast phase. Most cancers also do not require multiple post-contrast phases through the chest. As a rule, a single-phase chest CT is sufficient for primary and metastatic intrathoracic diseases. Unfortunately, as explained earlier, abdomen-pelvis CT protocols often over-use multiphase CT acquisitions. Oncologic baseline and follow-up CT protocols must be carefully reviewed and parsed into two groups.

Group 1- single-phase abdomen-pelvis CT oncologic protocol: This should be the most common CT protocol that requires only the portal venous phase coverage and should be used for most cancers such as head and neck cancer (excluding melanoma and thyroid cancer), lung cancer, breast cancer, sarcomas (excluding angiosarcoma), lymphoma, leukemia, gastrointestinal cancers (excluding carcinoid), male and female reproductive organs' cancers.

Group 2 – Multiphase (2-4 phases) abdomen-pelvis CT oncologic protocol: These protocols can include hypervascular malignancies and lesions (such as melanoma, carcinoid, thyroid cancer, and focal liver, renal, pancreatic, and adrenal lesions).

8. MULTI-BODY PART PROTOCOLS

Several vascular, trauma and oncologic indications require simultaneous scanning of contiguous body parts in the same imaging session. Such multi-body part imaging protocols are often associated with high radiation doses due to long scan lengths and frequent multiphase acquisitions. Vascular indications (such as suspected or known aortic aneurysm or dissection) require a single-run acquisition across the chest and abdomen (from the top of the thorax to the pubic symphysis). When performed as triple-phase CT with non-contrast, CT angiography in arterial phase, and two-minute delayed phase, these exams often have some of the highest radiation doses. Therefore, it is prudent to divide the protocols into low-risk, non-surgical patients' group with aortic aneurysm initial diagnosis and follow-up where a single arterial phase is usually sufficient, and the other group with higher risk, older patients with either suspected dissection or post-surgical repairs where two or three phase CT protocol is appropriate.

For patients with trauma undergoing multi-body CT protocols, prior publications have reported on using split-bolus contrast injection techniques to reduce the number of post-contrast acquisition phases and radiation doses [106-109]. With split-bolus contrast injection, intravenous contrast media are injected in two or more boluses, with the early contrast bolus providing venous or parenchymal enhancement and the latter contrast bolus providing arterial or vascular enhancement in a single-phase CT acquisition.

Multi-body part CT protocols are associated with relatively high radiation doses, and it is important that such protocols avoid multiphase acquisitions, particularly in young patients or those without oncologic diseases. In oncologic patients, avoiding unnecessary non-contrast phases can help reduce radiation doses and with the mandatory use of AEC to adapt tube current over changing body attenuation along longer scan lengths. When performing multibody part CT over continuous anatomic regions, it is important to consider the number of "runs." A single

run refers to a single scan acquisition through the entire scan range (such as with chest-to-pelvis coverage for chest-abdomen-pelvis CT). It avoids overlapping scan lengths between continuous body parts but requires longer breath-hold on older scanners with a greater possibility of suboptimal contrast enhancement over at least some parts of the anatomy. When performing multi-run acquisition, contrast enhancement in each part can be optimized while substantially reducing radiation dose for some parts (such as chest at >/= 50% lower radiation dose compared to abdomen-pelvis CT) with scan factor modifications. For example, with the use of lower tube current and potential for chest CT acquisition versus the abdomen-pelvis acquisition.

9. CONCLUSION

The document highlights several ways to implement clinical indication-based implementation of justification and optimization in CT. The learning objectives of the document can be summarized as:

1. Correct and complete clinical indications or reasons profoundly affect the justification and radiation dose optimization of CT.

2. Clinical indications must be available when ordering an exam and scanning any patient.

3. Regulators, hospital administration, referring physicians, and imaging physicians must create and enforce policies around the availability of clinical indications.

4. Although a digital system for relaying clinical indications for ordered imaging examinations is the preferred option, a manual but auditable system can be implemented in sites without digital infrastructure and resources.

5. Sites must create and save clinical indications-driven CT protocols that link scan factors and techniques to optimize acquisition technique and radiation doses.

6. “One-protocol-per-body-region-and-all-indications” defeats the purpose of optimization in CT and should be discouraged.

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IAEA RER9157 project "Strengthening Implementation of the Justified and Optimized Use of Ionizing Radiation in Medicine" counterparts:

Ms Brikena Vucaj, ALBANIA

Mr Karen Haroyan, ARMENIA

Ms Irma Coralic, BOSNIA AND HERCEGOVINA

Ms Jana Nikolaeva Djounova, Ms Deyana Stoyanova Dosieva, BULGARIA

Ms Larisa Rozdyalouskaya, BELARUS

Mr Dario Faj, CROATIA

Mr Demetrios Sakkas, CYPRUS

Ms Jelena Subina, ESTONIA

Ms Maia Topeshashvili, GEORGIA

Mr Christos Pafilis, GREECE

Ms Terez Sera, HUNGARY

Mr Tairkhan Dautov, KAZAKHSTAN

Ms Anna Kulikova, KYRGYZSTAN

Ms Marite Caikovska, LATVIA

Mr Julius Ziliukas, LITHUANIA

Ms Jasminka Chabukovska-Radulovska, NORTH MACEDONIA

Mr Nolan Vella, Ms Nadine Napoli, MALTA

Ms Sonja Ivanovic, MONTENEGRO

Mr Ion Ursulean, REPUBLIC OF MOLDOVA

Mr Dariusz Kluszczynski, POLAND

Ms Paula Santos, PORTUGAL

Ms Preda Iuliana Stefania, ROMANIA

Mr Aleksandr Vodovatov, RUSSIAN FEDERATION

Mr Dejan Žontar, SLOVENIA

Ms Veronika Drábová, Mr Igor Gomola, SLOVAKIA

Ms Snezana Alempijevic, SERBIA

Mr Safarali Muminov, TAJIKISTAN

Mr Gökçe Kaan Ataç, TÜRKIYE

Ms Nataliia Bilokin, UKRAINE

Ms Marina Vladimirovna Li, UZBEKISTAN