Computed Tomography

Advanced Clinical Applications

Shayne Chau
Christopher Hayre
Editors

Springer

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Dr. Hayre would like to dedicate this book to his wife, Charlotte and daughters, Ayva, Evelynn and Ellena. Love to all.

Shayne Chau would like to dedicate this book to his parents and brother. To my wife, Jo, I can find no words that can express my endless affection and gratitude.

Foreword

Computed Tomography is a dynamic technology and as such it keeps evolving at a rapid pace, producing technical innovations that play a significant role in the medical care and management of the patient. These recent developments have also facilitated more advanced clinical applications, which is the subject matter of this book; *Computed Tomography: Advanced Clinical Applications*, edited by Shayne Chau and Dr. Christopher M. Hayre. Chris is the Editor in Chief for the Journal of Social Sciences and Allied Health Professions, and Social Media Editor for the reputable journal, Disability and Rehabilitation. In addition, both Shayne and Chris have years of experience in teaching in medical imaging at both undergraduate and graduate degree programmes, and as such they have gained worldwide respect as medical imaging educators.

This text provides a useful insight into understanding advanced clinical applications described in four sections of this text, namely: Radiobiology and Patient Care; CT in an Emergency Setting; CT-Guided Interventions; CT Forensic Imaging; and CT in Education. There are 11 chapters authored by well-respected authors in the field of CT. In this regard, they have now presented yet another textbook which will be a worthwhile in addition to the CT literature. Both radiologists and radiographers will appreciate the vast amount of current information on the topics covered in this text, and this book offers the opportunity for them to enhance their clinical practice skills and ultimately improve the care of the patient undergoing CT examinations.

Chris is a Senior Lecturer at the University of Exeter and holds a Senior Fellowship with the University of Suffolk. He also serves as a Research Associate for the University of Johannesburg. Shayne is currently a Senior Lecturer in Medical Imaging at the University of Canberra, Australia. Furthermore, Chris is a prolific editor for Medical Imaging textbooks, and he has championed a new book series called Medical Imaging in Practice intended to provide “a sound understanding of key and emerging topics relating to general imaging, computed tomography, magnetic resonance imaging, nuclear medicine, mammography, ultrasonography, patient care and image interpretation”. Several notable examples in the series includes *General Radiography: Principles and Practice; Research Methods for Student Radiographers: A Survival Guide; and Computed Tomography: A Primer for Student Radiographers.* This series is published by CRC Press (Taylor and Francis Group).

It is my sincere prediction that this book *Computed Tomography: Advanced Clinical Applications* will become one of the most important tools, not only for students studying CT, but also for those working in clinical practice. Additionally, colleges and universities delivering medical imaging education should have copies in their libraries.

Shayne and Chris have done an excellent job in covering these advanced clinical applications in Computed Tomography.

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The editors would like to thank all contributors for their dedication towards this advanced text. This book invited contributions from advanced practitioners in the computed tomography. This has resulted in high-quality chapters providing insight into contemporary practices. It has been a pleasure to work with peers worldwide, emphasizing an international appeal to radiographers. Finally, the editors agree that this has been an exciting and prosperous project, which we hope readers utilize in both clinical and academic spaces.

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Part I

Radiobiology and Patient Care

Radiobiology and Radiation Protection

Abel Zhou

Abstract

This section provides an overview of ionizing radiation exposure and radiation protection using computed tomography (CT). Patients undergoing CT examinations as part of their diagnosis or treatment are exposed to ionizing radiation. A net benefit is justified for patients against potential risks induced by exposure to ionizing radiation. This section contains two main subsections: (1) radiobiology and radiation protection and (2) radiation dose in CT examinations. The first subsection reviews the interactions between ionizing radiation and matter, biological effects of ionizing radiation, causative relationship between radiation exposures and their effects, and radiation protection methods. The second subsection systematically reviews radiation measurements with a special focus on CT dose metrics and discusses their applications and limitations.

Keywords

Deterministic effect · Stochastic effect · Linear no-threshold (LNT) · Radiation protection · CT dose index (CTDI) · $\mathrm{CTDI}_{\mathrm{FDA}}$ · CTDI_{100} · $\mathrm{CTDI}_{\mathrm{W}}$ · $\mathrm{CTDI}_{\mathrm{vol}}$ · Dose-length product (DLP)

1 Radiobiology and Radiation Protection

Ionizing radiation interacts with the tissues of the human body and can lead to cell damages, such as cell death or changes in cell function. Radiobiology is the study of the effects of ionizing radiation on living organisms. Ionizing radiation is named because of its capability to eject an orbiting electron from its atom. Medical X-ray imaging uses high-energy photons to produce diagnostic or guidance information for the management of diseases. The use of X-ray imaging is regulated owing to its potential health risks, which are minimized by radiation professionals while maximizing the benefit of undergoing an X-ray imaging examination.

1.1 Interactions Between Photons and Matter

Radiation, an energy packet traveling in space at the speed of light, is an electromagnetic wave possessing an electric field and a magnetic field. Radiation is commonly known as photons and is measured in electron volts (eV), kiloelectron volts (keV), or megaelectron volts (MeV). The terms radiation, X-rays, and photons are used interchangeably in X-ray imaging. Photons may also be measured in terms of the wavelength by the relationship $\lambda = h \times c \div E_{\mathrm{ph}}$. Here, λ is the

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wavelength, h is the Planck constant ($6.62607004 \times 10^{-34}$ m^{2}kg/s or J/s), c is the speed of light in vacuum (2.99792458×10^8 m/s), and E_{ph} is the energy in J. For example, the wavelength of a 124-eV photon is approximately 10 nm. Wavelength measurements of photons are uncommon in X-ray imaging.

Photons with energies above the binding energy of an orbiting electron can eject an electron from its atom. In X-ray imaging, the X-ray beam consists of many polychromatic photons whose energy ranges from approximately 10–150 keV. The minimum and maximum energies depend on the total filtration and tube voltage, respectively. Photons of these energies can interact with tissues through three interaction models: Rayleigh scattering, Compton scattering, and photoelectric absorption. The interactions between photons and matter are also known as attenuation. The probability of each interaction has a coefficient that is available from the NIST (2004). Interaction probabilities depend on several factors: photon energy, tissue composition, density, and thickness. The total mass attenuation coefficients of soft tissue, bone cortical, and brain are illustrated in Fig. 1 for photon energies from 10 to 150 keV.

An X-ray beam traversing through tissues reduces the total number of primary photons along the path. The reduction of primary photons follows the Bouguer (1729)–Lambert (1760)–Beer (1852) exponential attenuation law expressed in Eq. (1), for a homogenous medium and monoenergetic X-ray beams.

$$I_l = I_0 \times e^{\left(-\frac{\mu}{\rho}\times l\right)} \tag{1}$$

where I_l is the number of photons traversing a distance l in the homogeneous medium without interactions, I_0 is the number of monoenergetic photons entering the medium, μ and ρ are the linear attenuation coefficient and density, respectively, of the medium, and e is the Euler's number, an irrational number approximately equal to 2.71828.

1.1.1 Rayleigh Scattering

Rayleigh scattering or coherent scattering occurs when an incident photon is deflected by the electromagnetic field inside an atom. The photon changes its trajectory, and its energy is preserved. The incident photon interacts with the atom and its orbiting electrons as a whole, leading to a change in its direction (Fig. 2). No electrons are ejected, and the atoms are not ionized. Rayleigh scattering dominates in low-energy X-ray photons, such as those used in mammography. When traversing through a 10-cm soft tissue, an X-ray beam of radiation quality RQT 8 (IEC 60627: 2005)–100 kilovoltage peak (kVp), 0.2 mm Cu added filtration, and 6.9 mm Al first half-value layer, will have approximately 10% of photons

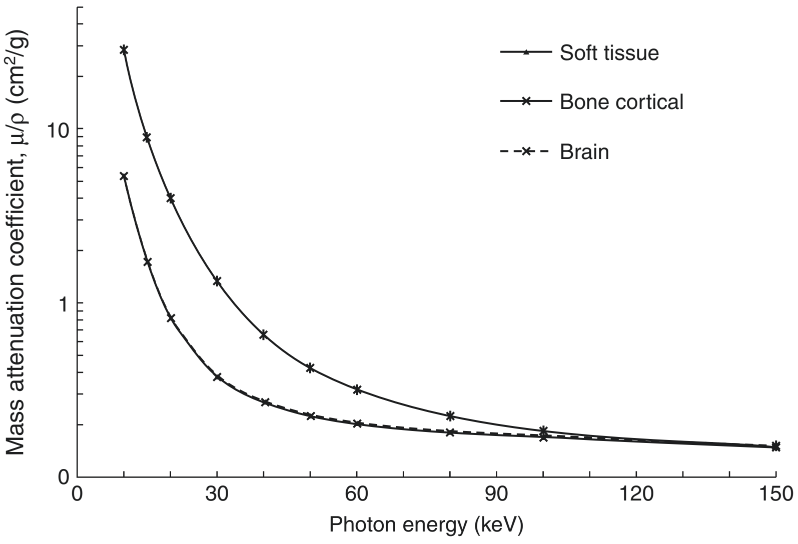

Fig. 1 Total mass attenuation coefficients (μ/ρ) of soft tissue, bone cortical, and brain for photon energies from 10 to 150 keV. μ and ρ are the linear attenuation coefficient and density, respectively

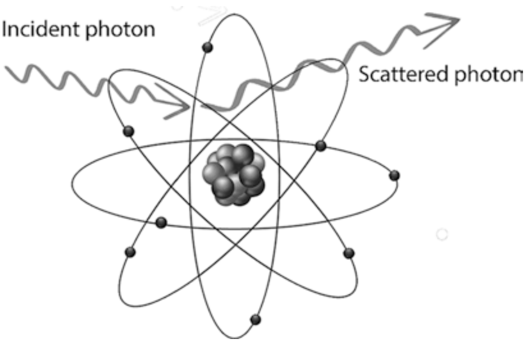

Fig. 2 Rayleigh scattering—the orbiting electrons and the atom interact as a whole with an incident photon and changes its direction without causing energy loss

undergoing Rayleigh scattering, more than 50% undergoing Compton scattering, while approximately 20% undergo photoelectric absorption.

1.1.2 Compton Scattering

Compton scattering, also known as inelastic scattering, was discovered by Arthur Holly Compton. In Compton scattering, an incident photon interacts with an orbiting electron, loses energy, and changes its direction (Fig. 3). A part of the energy of the photon is transferred to the electron, which gains kinetic energy and escapes from the atom. The sum of the kinetic energy and the binding energy of this electron equals the energy lost by the photon. The direction of the electron is confined to an angle that is not more than π/2 rad with respect to the original direction of the photon. During Compton scattering, photons are more likely to interact with loosely bound or outer-shell electrons. Compton scattering results in scattered radiation and ionization.

1.1.3 Photoelectric Absorption

Photoelectric absorption or the photoelectric effect is the process that an orbiting electron absorbs a photon and escapes from the atom. The electron absorbs all the energy of the photon and escapes from the atom with a kinetic energy equal to the difference between the energy of the photon and the binding energy of the electron (Fig. 4). Photoelectric absorption occurs only if the photon energy exceeds the electron binding energy. A photon is most likely to interact with the electrons whose binding energies are the closest to, but less than its energy. Photons with energies exceeding the K-shell binding energy are most likely to interact with the K-shell electrons through photoelectric absorption. After a K-shell electron is ejected, the atom is ionized with a K-shell electron vacancy. This vacancy can be filled by an electron from a nearby shell with a lower binding energy (in this example, the L-shell). The electron filling this vacancy, however, can be from any outer shell, for example, the M shell or N shell. As the electron escapes from its orbit, it creates

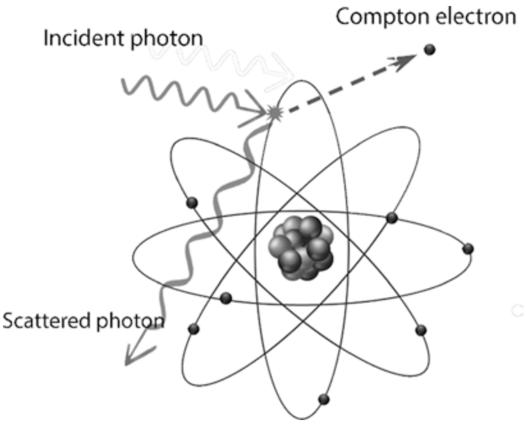

Fig. 3 Illustration of Compton scattering. An incident photon interacts with an orbiting electron. The photon loses some energy and is deflected away from the incident direction. The electron is ejected with a certain kinetic energy

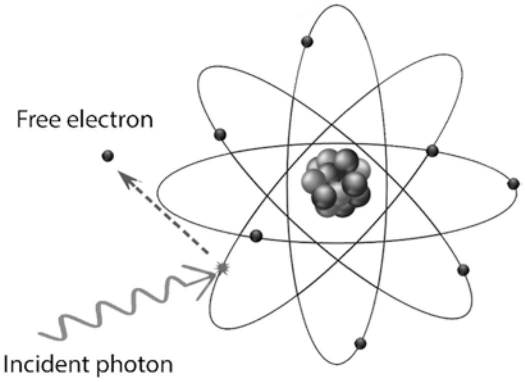

Fig. 4 Illustration of photoelectric absorption. An incident photon is absorbed by an orbiting electron. The electron is ejected with a kinetic energy equal to the difference of the energy of the incident photon energy and the binding energy of the electron

another vacancy, which is then filled with an electron from an even lower binding energy shell. Thus, an electron cascade from the outer shells to the inner shells occurs. In an electron cascade, the difference in binding energy is released as photons, which are known as characteristic X-rays. A bound electron, possibly from the same shell of the cascading electron, can absorb a characteristic X-ray emitted by the cascading electron. After absorbing the X-ray, this bound electron escapes from the shell and is known as an Auger electron (first discovered by Meitner (1922)). The emission of Auger electrons and characteristic X-rays are competing processes. The probability of the emission of characteristic X-ray decreases as the atomic number of the material decreases. Soft tissues are mostly composed of materials with low atomic number. Characteristic X-ray emission does not frequently occur in soft tissues, but Auger electron emission predominates.

1.1.4 Pair Productions

Photons with energy of at least 1.022 MeV may undergo pair productions with a strong electric field from the nucleus. In a pair production interaction, the photon energy is completely absorbed by the nucleus, resulting in the production of an electron and a positron. The electron and positron have the same energy and are separated by 180° or move in opposite directions.

1.2 Effects of Ionizing Radiation

Interactions between photons and matter result in energy deposition in tissues and damage cells. At the atomic level, these interactions can break chemical bonds, relocate atoms within cell molecules, and lead to change or loss in the function of the molecule and damage cells. Damaged cells may repair themselves correctly and survive. They may incorrectly repair themselves and die. If they survive, they can progress to abnormality or they may not manifest any abnormalities during the lifetime of the person. The effects of ionizing radiation on humans can be deterministic or stochastic.

1.2.1 Deterministic Effects

Deterministic effects include acute damages to the organs and tissues. Damages often occur in the form of the loss of tissue or organ functions, such as cell death and, in extreme cases, death of the irradiated individual. Deterministic effects have threshold doses and occur when the dose exceeds the threshold dose. Some threshold doses are listed in Table 1. Threshold doses depend on the type of irradiated organ/tissue and type of clinical effects on the organ/tissue exposed. If the radiation dose received by an individual exceeds the threshold dose, the severity of the deterministic effect increases as the dose increases. The threshold doses may be revised with an increasing number of observations for deterministic effects. There is much evidence to show that radiation-induced eye cataracts and circulatory diseases occur at lower radiation doses than previous estimations.

1.2.2 Stochastic Effects

Stochastic effects include cancerous and non-cancerous risks for irradiated individuals and heritable risks passed on to their offspring. Following

Table 1 Threshold doses for the incidence of morbidity in tissues and organs in adults exposed to acute or chronic irradiation

Effect	Organ/ tissue	Time to develop effect	Acute exposure (Gy)	Annual (chronic) dose rate for many years (Gy/year)
Temporary sterility	Testes	3–9 weeks	~0.1	0.4
Permanent sterility	Testes	3 weeks	~6	2.0
Permanent sterility	Ovaries	<1 week	~3	>0.2
Depression of hematopoiesis	Bone marrow	3–7 days	~0.5	>0.4
Cataract (visual impairment)	Eye	>20 years	~0.5	~0.5 divided by years duration

radiation exposures, stochastic effects occur by probabilities, and there is no guarantee that an irradiated individual will develop any signs or symptoms of diseases. There is a latent period before any signs or symptoms manifest. Cancerous risks result from damages to genes by direct or indirect energy depositions in deoxyribonucleic acids (DNAs). Cells have several repair mechanisms that correct themselves during cell division cycles. Unrepaired or wrongly repaired DNA damages may cause cancers in irradiated individuals. These are known as somatic effects. If the damages result in a disease in the offspring of the irradiated individual, it is known as a heritable effect. Heritable risks of radiation exposures are observed among the offspring of Japanese atomic bomb survivors. Non-cancerous risks include cataracts, atherosclerotic diseases, inflammatory responses, and myocardial infarction (Little et al. 2008b; Baker et al. 2011; Picano et al. 2012).

Stochastic effects are proportionally related to the cumulative radiation dose of an individual. The severity of the stochastic effects is not related to the dose. A cancer induced by 2 Gy is not worse than that induced by 0.1 Gy. Stochastic effects have no threshold doses. A single instance of an unrepaired DNA damage can cause cancers or hereditary defects, though with a very low probability (Mossman 2006). The best practice in X-ray imaging involves keeping radiation exposures as low as reasonably achievable (ALARA) to minimize stochastic effects.

1.2.3 Evidence of Ionizing Radiation Effects

On July 31, 2010, the New York Times reported Walt Bogdanich's findings about adverse clinical symptoms including hair loss, headaches, memory loss, and confusion in patients who underwent CT brain perfusion scans because of the intentional use of high levels of radiation to obtain high-quality images. CT brain perfusion scans are performed to evaluate cerebral blood flow, such as in the diagnosis of stroke. More than 400 patients at eight U.S. hospitals might have been affected by brain perfusion scans. These symptoms were due to large acute radiation exposures and are typical examples of deterministic effects.

The stochastic effects of radiation exposure have been observed in a wide range of investigations, such as the increased incidence of cancers in the offspring of Japanese atomic bomb survivors (Little et al. 2009b), development of cancers in experimental animals, and the significantly high rates of cancers among irradiated populations. Significantly higher rates of breast cancers were reported among female patients with tuberculosis who underwent extensive diagnostic fluoroscopy and the incidence was found to be approximately 10–15 years after the initial examinations. Among the patients who received a low dose between 10 and 90 mGy, a significantly higher risk remained (Doody et al. 2000). Higher risks of breast cancers were also reported in patients who underwent radiation therapy for a mean dose of 290 mGy to the breast (Eidemüller et al. 2009, 2011). Similar results were observed in women who were treated for postpartum mastitis with doses typically ranging from 1 to 6 Gy (Hall and Giaccia 2019). An increase in lung cancers has also been reported in patients treated with radiation doses of 5 Gy or more (Travis et al. 2002; Dores et al. 2002). Leukemia is one of the malignant cancers that are most likely linked to radiation exposures. Leukemia is commonly diagnosed in X-ray workers, physicists, and engineers working near accelerators and other sources of ionizing radiation (Little et al. 2009a). The latest evidence of stochastic effects comes from a study of about 950,000 children and young adults (before age 22 years) of nine European countries. The study shows a significantly linear dose-response relationship for brain cancers after CT brain examinations (Hauptmann et al. 2023).

1.3 Linear No-Threshold Model

The risks of cancers owing to exposure to ionizing radiation have been widely observed and are unavoidable. A causative relationship between radiation doses and cancer risks is described by a linear no-threshold (LNT) model that is modeled on epidemiological and animal data (Little et al. 2008a). The LNT theory predicts that stochastic effects are proportional to cumulative radiation doses. The LNT model is established for high radiation doses with dose-specific estimates of risks determined from people exposed to acute doses of 200 mSv or greater.

In medical imaging, radiation exposure or fractionated exposures with acute fractions are less than a few mSv. It is difficult to detect cancer risks resulting from low radiation doses in epidemiological studies. ICRP (2007) it is generally accepted that the risks from LNT should be divided by the dose and dose-rate effectiveness factor (DDREF) to model the risks at low radiation doses. DDREF values for doses at or below 2 Gy have a value of 2. In comparison, the Biological Effects of Ionization Radiation (BEIR) Committee recommends DDREF values in the range of 1.1–2.3, based on the Bayesian statistics of the combination of the life span studies of atomic-bomb survivors and selected animal studies.

1.4 Radiation Protection

The stochastic effects of radiation exposure are modeled by the LNT theory. The best X-ray imaging practice is to keep radiation exposure ALARA, while producing optimal quality images. The primary goal of radiation protection is to prevent the occurrence of deterministic effects and minimize stochastic effects. In medical X-ray imaging, the principles of justification, optimization, and dose limits are recommended for radiation protection.

The **principle of justification** refers to the fact that every radiation exposure received by patients must be associated with a positive net benefit. The justification principle is intended for healthcare professionals who can prescribe X-ray imaging examinations. It is an effort to reduce radiation exposure to patients by avoiding unnecessary X-ray imaging examinations.

The **principle of optimization** is based on the ALARA principle. This means that all radiation exposures must be kept as low as reasonably achievable without compromising the image diagnostic quality, with economic and social factors taken into consideration. The practical implementation of the ALARA principle requires radiation professionals to apply relevant methods consistently to ensure that the amount of radiation is kept at the minimum while producing images with optimal quality. A practical challenge with the ALARA principle lies in producing acceptable image quality with the lowest possible radiation doses. **Dose limits** are set for regulatory guidance on radiation protection for radiation professionals. It states that the radiation dose a professional receives annually and accumulates over the professional practical period should not exceed the recommended dose limits. These limits are intended to prevent deterministic effects and reduce the stochastic effects of radiation exposure on radiation professionals.

The exposure time, distance from a radiation source, and shielding are essential factors for radiation protection. The total radiation exposure received by an individual is proportional to the exposure time and inverse square of the distance from the radiation source. **Minimizing the time** of exposure to ionizing radiation is an essential method for reducing the total radiation dose received by the individual. Healthcare professionals should minimize the time during which they have to be in areas where the generation of X-rays is active, for example, during CT fluoroscopy examinations. **Increasing the distance** from the radiation source is another important approach for reducing radiation exposure. During X-ray imaging, the radiation from the source is divergent and travels in all directions. The amount of radiation reaching a given area depends on its distance from the source and is proportional to the inverse square of the distance. Thus, the further the source, the less radiation the received. When a patient undergoes a CT examination, the body becomes a source of scattered radiation, which moves in all directions. During CT fluoroscopy examinations, healthcare personnel should stand at a reasonable distance from the scatter source. **The use of shielding** is another effective radiation protection method. Shielding is designed to reduce radiation exposure to personnel. Shielding devices are made of high atomic number materials, such as lead plastics, to absorb radiation. Personal shielding devices commonly include lead aprons, gloves, goggles, and thyroid shielding. Transparent plate-glass shielding can be used to protect personnel from scattered radiation without limiting vision. The CT room walls are shielded to protect persons from exposure to scattered radiation. Shielding may not be intended for patients; it could not protect the patient from exposure to scattered radiation arising from herself/himself. For the patient, shielding is only useful if it is used to stop the primary beam. If the primary beam must be stopped, beam collimation should first be used to exclude regions where the shielding would have been applied.

1.5 Image Quality Optimization and Dose Reduction

Several techniques are used to reduce radiation exposures to patients and improve image quality. These include beam filtration, collimation, current modulation, automatic exposure control, patient centering, and noise reduction reconstruction algorithms. X-ray beam **filtration** reduces the number of low-energy photons, leading to an increase in the average beam energy. Filtration devices can be applied to deliver radiation in the most appropriate distribution over gantry angles with regard to the regions and shapes of the irradiated anatomy. Beam filtration devices are applied between the X-ray tube and the patient. Some manufacturers have also used filters specific to patient size and/or cardiac CT examinations. **Beam collimation** is applied to limit the beam to the minimal dimensions required. Beam collimation occurs along the *z*-axis to define the body length to be scanned and across the patient table to define a scan field of view (SFOV).

Tube current modulation and **automatic exposure control** (ACE) are used to adjust the radiation exposure in response to variations in imaging object sizes and shapes in real time during data acquisition. Some manufacturers adjust the current based on attenuation changes along the *z*-axis while others control the current by attenuation changes with respect to the gantry rotation (in the *x*–*y* plane). Others combine both approaches to achieve a predetermined image noise level by controlling the current. The application of tube current modulation and AEC is a common radiation dose reduction method found in modern CT scanners.

Patient centering in CT scans, which affects the radiation dose to the patient, is controlled by radiation professionals. Inaccurate centering mostly occurs in the vertical direction (y-axis) owing to too low or high patient table positions and is less frequent for patients lying to the side of the table (x-axis). Occasionally, patients may be off-centered in both directions. Ideal centering requires the patient to be centered on the gantry's iso-center for data acquisition and accurate imaging. Off-centering can lead to partial scan coverage (Fig. 5), increase patient radiation doses, and degrade image quality. With a CT body phantom, a 3-cm off-centering and a 6-cm off-centering resulted in an increase in the patient dose by 18% and 41%, respectively (Li et al. 2007; Toth et al. 2007; Kataria et al. 2016). Off-centering can

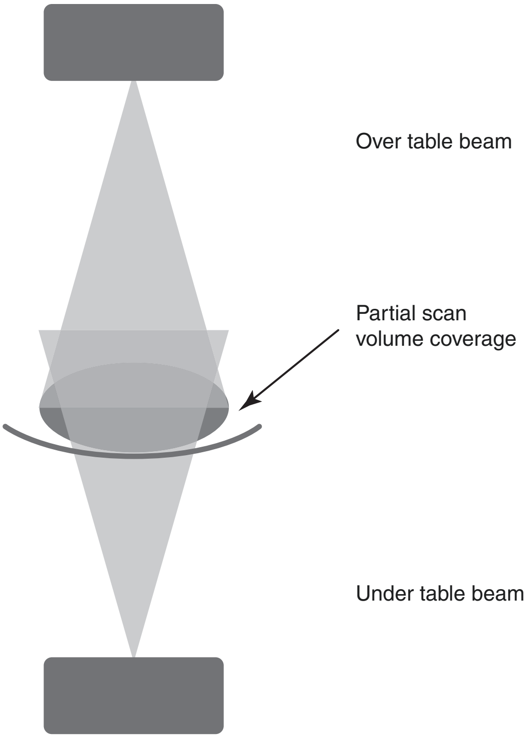

Fig. 5 Illustration of off-centering in the vertical direction. Off-centering can cause partial scan volume coverage, resulting in increased noise and reduced image quality

affect the CT numbers or Hounsfield numbers (HU). CT numbers are converted from linear attenuation coefficients, which are calculated from the sinogram data acquired during the scan. CT numbers are whole numbers truncated from the results calculated using Eq. (2). CT numbers are relative to the linear attenuation coefficient of water. The CT number of water is always zero. Changes of more than 20 HUs were found in a 10-cm off-centering from the iso-center. The majority of off-centering in clinical CT examinations was less than 2 cm and less than 2% of examinations exhibited an off-centering exceeding 4-cm (Szczykutowicz et al. 2017).

$$\mathrm{HU} = 1000 \times \frac{\mu_{\text{tissue}} - \mu_{\text{water}}}{\mu_{\text{water}}} \tag{2}$$

where HU is the Hounsfield number, and μ_{tissue} and μ_{water} are the linear attenuation coefficients of the tissue and water, respectively.

Noise reduction reconstruction algorithms use iterative procedures to reduce image noises. The traditional filtered back projection (FBP) reconstruction method produces high-quality images from data acquired with optimal radiation exposure. For low radiation exposures, the FBPs of most manufacturers fail to reduce image noises and result in poor image quality. Iterative reconstruction (IR) algorithms are generally more useful for image reconstruction at low or ultra-low radiation exposures (Willemink and Noël 2019; Willemink et al. 2014). Many CT manufacturers offer IR algorithms along with their new CT scanners. During the last decade, artificial intelligence (AI) algorithms with the potential for high image quality at ultra-low radiation exposures have emerged for CT image reconstruction. Most IR algorithms fall into two major categories: hybrid and model-based. Hybrid IR algorithms first iteratively filter the sinogram data to achieve noise reduction and then perform back projection. After back projection, the image data are iteratively filtered to reduce image noises. Model-based IR algorithms first perform backward projections to obtain the image data and then perform forward projections to produce artificial sinogram data. The artificial sinogram data are then compared to the real sinogram data, and their differences are used to update the image data. This iteration continues until a predefined condition is reached. A convolutional neural network (CNN) algorithm has shown great success in reducing image noises and the effect of scatter radiation (Zhou et al. 2020). The fundamental advantage of AI is machine learning, in which the algorithm can produce a mapping from raw inputs to specific outputs. CNN algorithms trained with low-dose CT image data have been tested using routine-dose CT images (Wolterink et al. 2017; Chen et al. 2017a,b). AI is expected to play a major role in the reconstruction of CT images. IR algorithms have been proven to be a great technique available in clinical practice for noise reduction.

2 Radiation Dose in CT Examinations

The LNT model quantitatively predicts the causative relationship between cancer risk and radiation exposure. The measurements of radiation delivered to patients are useful for risk assessment in X-ray imaging. The effects of ionizing radiation on tissues depend on several factors, including the amount of energy deposited in the tissue, the type of radiations, and the type of tissues. For the same radiation dose, different types of radiations can have different degrees of effects on tissues. A radiation weighting factor (Table 2) is used to account for the relative biological effectiveness (RBE) of different types of radiations. A tissue weighting factor (Table 3) is used for the radiosensitivity of tissues. Radiation measurements also consider other factors that affect the biological effects. Several radiation measurements are used in X-ray imaging, and some of them are dedicated to CT examinations.

Table 2 Radiation weighting factors

Radiation type	Radiation weighting factor, $W_R{}^{\#}$
Photons, electrons	1
Protons	2
Alpha particles	20
Neutrons (a function of the energy)	5–20

Table 3 Tissue weighting factors

Tissue	W_T, individual	$\sum W_T$[#]
Bone red marrow, colon, lung, stomach, breast, remainder tissues[a]	0.12	0.72
Gonads	0.08	0.08
Bladder, esophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04
	Total	1.00

[a] Remaining tissues: adrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (M), small intestine, spleen, thymus, uterus/cervix (F)

2.1 Absorbed Dose

The amount of energy deposited per unit mass is known as the absorbed dose (Eq. 3), and its SI unit is Gray (Gy) or J/kg. The absorbed dose is one of the most frequently used radiation measurements in X-ray imaging and can be measured with a dosimeter, such as an ionization chamber.

$$D = \frac{\varepsilon}{m} \tag{3}$$

where D is the absorbed dose in Gy (or J/kg), and ε is the energy deposited in a mass of m kg.

2.2 Effective Dose

The effective dose accounts for the biological effects owing to energy deposition, radiation type, and tissue type. To calculate the effective dose, the absorbed dose is ideally measured with a uniform radiation beam exposing the whole body. The effective dose (E) is calculated using Eq. (4), which is the product of the absorbed dose (D), radiation weighting factor (W_R), and tissue weighting factor (W_T).

$$E = W_R \times W_T \times D \tag{4}$$

The effective dose is intended for radiation protection, such as radiation dose assessments for occupationally exposed personnel and planning and optimization in radiological protection. It is a statutory quantity for demonstrating compliance with dose limits and cannot be used to assess individual risks. The effective dose is recommended neither for epidemiological evaluations nor for the detailed specific retrospective investigations of individual exposures and risks.

The application of an effective dose in medical X-ray imaging has limitations. The effective dose facilitates the comparison of biological effects between different types of diagnostic examinations. The effective dose may be used to communicate with patients concerned about the potential harm of their X-ray imaging examinations. The effective dose has an advantage and can be compared to the annual effective dose from naturally occurring background radiation. It varies from region to region and is approximately 3.0 millisievert (mSv) in the United States or 1.5 mSv in Australia.

Controversies over effective dose values may arise because of the calculation methodology and data sources. The effective dose is a measure of the relative "whole-body" uniform radiation exposure, which differs from the exposure to a divergent X-ray beam generated in X-ray imaging. In addition, X-ray imaging examinations often include only a part of the body, variations in the calculation of effective doses for X-ray imaging examinations occur.

2.3 Organ Dose

Organ dose is useful when radiation protection of individual organs is considered. The organ dose is the total energy deposited in an organ divided by its mass. The unit for organ dose is Gy. The direct measurement of organ doses is impractical. They can be appropriately determined using Monte Carlo simulations or experimental setups with phantoms.

2.4 Exposure

Radiation exposure is a measure of the number of electrical charges of a single sign that is produced by ionizing radiation per unit mass of gas, for example, air. Exposure is based on the fact that for each gas, the average energy needed to ionize one pair of ions is constant. For example, the average energy needed to create one pair of ions in air is approximately 34 eV.

Radiation exposure can be directly measured with air-filled radiation detectors for biological purposes because the effective atomic number of the air is close to that of soft tissues. Radiation exposure is nearly proportional to the absorbed dose in soft tissues over the range of photon energies used in medical X-ray imaging. The unit of radiation exposure may be expressed as Roentgen (R) or coulomb per kilogram (C/kg). Exposure can be converted to the absorbed dose. One *R* is approximately 8.73 mGy.

2.5 Dose Distribution in SFOV

Contiguous irradiation during gantry rotations contributes to the radiation dose at a location in the SFOV because of scatter radiation, collimation diaphragms, and geometry of the focal spot. The distributions of radiation doses in the SFOV for small and large imaging objects are illustrated in Figs. 6 and 7, respectively. The radiation doses were higher in the peripheral regions and lower toward the central regions for both the 16-cm diameter head phantom and the 32-cm diameter torso phantom. The distributions also depend on the tube kVp; generally, the lower the kVp, the greater is the difference between the peripheral region doses and the central region doses (Imhof et al. 2003; Geleijns et al. 2009) owing to the greater radiation attenuation of lower energy photons.

2.6 Dose Distribution Along Scan Length

The radiation reaching a location in the SFOV depends on the scattered radiation from the planned scan volume and the geometries of the X-ray focal spot and collimation diaphragms. The radiation dose can be modeled from the radiation distribution of a single-slice scan. In a single-slice scan, an ideal distribution of radiation along the scan length (z-axis) through any point in the SFOV is a square-wave (Fig. 8b) because of the perfect point source (an infinitely

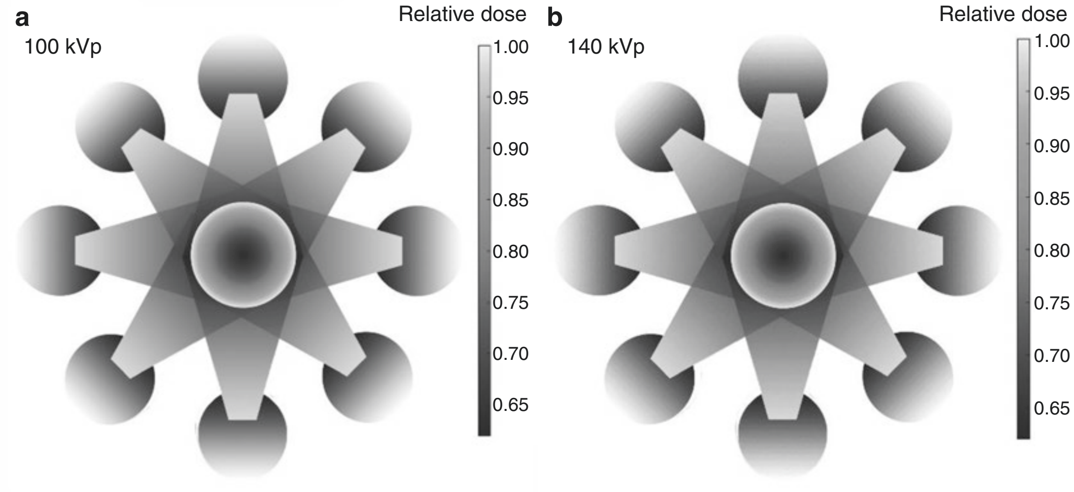

Fig. 6 Radiation dose distributions in a 16-cm diameter head phantom. The doses decrease from the peripheral to the central regions. The doses in the peripheral regions are about 1.5 times the doses in the central areas for both the 100-kVp (**a**) and 140-kVp (**b**). The radiation dose information is from Imhof et al. (2003)

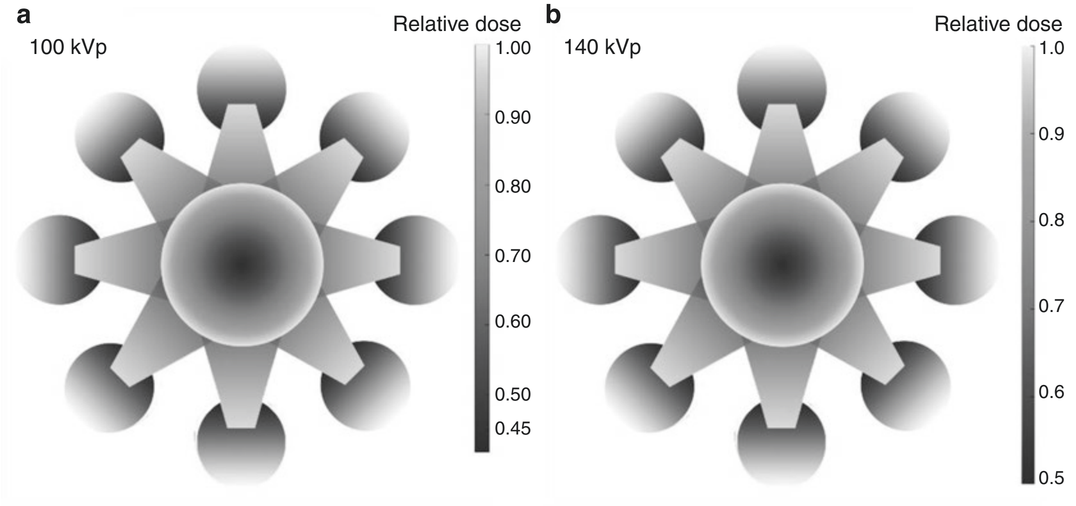

Fig. 7 Radiation dose distribution in a body phantom of 32 cm in diameter with higher doses at the peripheral regions and lower doses at the central region. (**a**): For 100-kVp, the peripheral area doses are about 2.4 times the doses in the central regions. (**b**): For 140-kVp the peripheral doses are about twice the doses in the central regions. The radiation dose information is from Imhof et al. (2003)

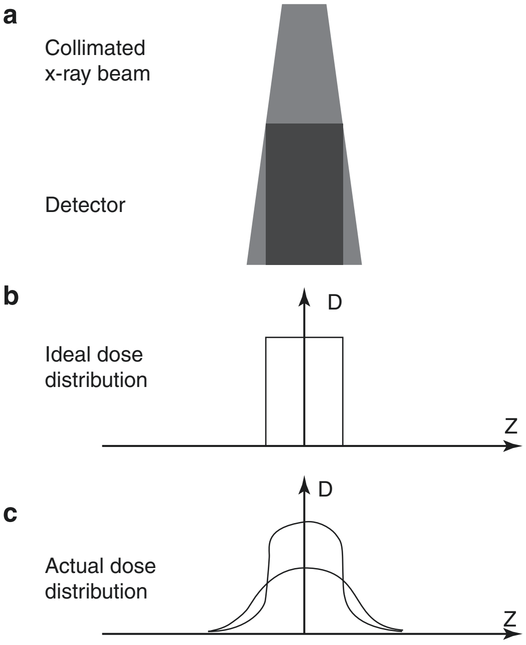

Fig. 8 Distribution of radiation along the scan length (z-axis) from a single-slice scan. (**a**) represents the detector with the collimated x-ray beam source. At any point in the SFOV (the x–y plane), an ideal distribution along the z-axis is a square-wave (**b**). An actual dose distribution closely resembles a narrow bell shape along the z-axis through a point in peripheral regions of the SFOV and broad bell shape along the z-axis through a point in central regions of the SFOV (**c**)

small focal spot) and lack of scattered radiation. The actual radiation distribution is nearly bell-shaped, forming a narrow bell along the scan length through a point in peripheral regions of the SFOV, and a broad bell along the scan length through a point in the central regions of the SFOV (Fig. 8c) (Geleijns et al. 2009).

CT radiation dose assessments are performed under standardized conditions that provide clinical geometries. A small phantom with a diameter of 16 cm and a large phantom with a diameter of 32 cm were used to simulate a patient's head and a torso/body, respectively (Fig. 9). Both phantoms, made from solid acrylic, were drilled with holes at specific locations for placing the pencil dosimeters. When radiation detectors are not placed in the holes, they are plugged using acrylic plugs.

2.7 CT Dose Index

The CT dose index (CTDI) measures the absorbed dose in CT examinations. The CTDI is intended to account for the radiation from a series of adjacent scans by measuring the radiation dose distribution from a single gantry rotation scan. The

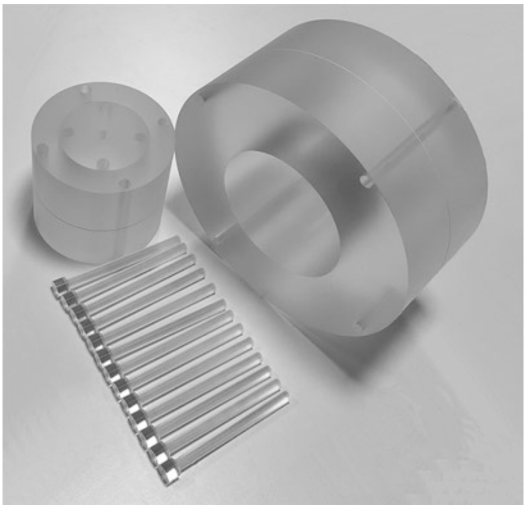

Fig. 9 CT cylindrical acrylic phantom for head and torso radiation dose measurements. The phantom comprised of three cylindrical parts and 13 acrylic plugs which are assembled with an outer diameter of 32 cm for torso dose measurements. The two inner cylinders are assembled with an outer diameter of 16 cm for head dose measurements. The cylinders are 15 cm high with 13 holes drilled through: four holes on the periphery of each cylinder and a central hole on the smallest one

CTDI model is given in Eq. (5). The CTDI is measured in Gy (or J/kg).

$$\mathrm{CTDI} = \frac{1}{nT}\int_{-z}^{z} D(z)\,dz \tag{5}$$

where n is the number of slices acquired in a single gantry revolution (for single-slice scanners, $n = 1$; for multiple-slice scanners, n depends on the activated data channels used for data acquisition with n = no. of active channels, and one channel is for one image slice). T is the width of a single slice along the z-axis. In single-slice scanners, T is the slice thickness. In multiple-slice scanners, where several detector elements may be grouped together to form one data channel, T is the width of one data channel, and nT is the effective beam width. z is the location along the direction of movement of the patient table. It has a range of values to cover a longer length than the single-slice scan length to measure the radiation dose due to the scan of the multiple slices. $D(z)$ is the dose at location z.The integration in Eq. (5) calculates the area under the dose curve (Fig. 10a).

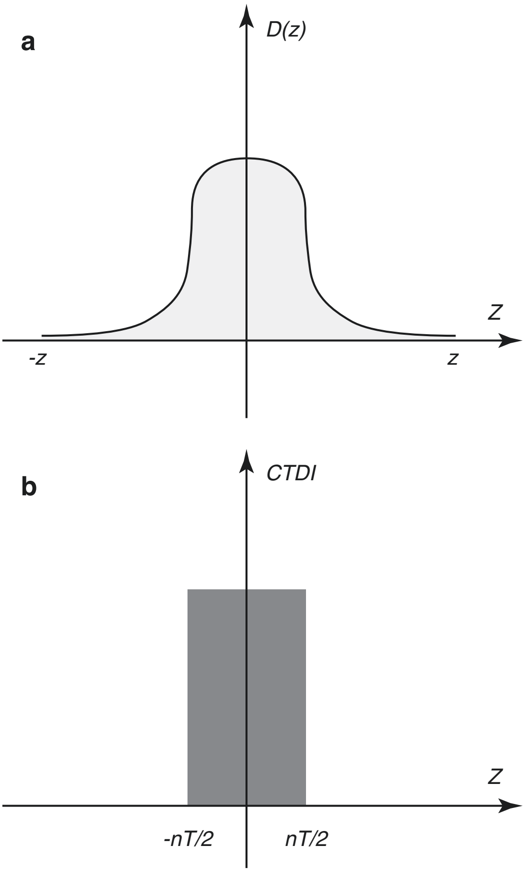

Fig. 10 Illustration of the equivalent area under the curve. (**a**) demonstrates the distribution of the radiation dose along the z-axis resulting from a single-slice scan; (**b**) shows a square-wave CTDI distribution over the X-ray beam width of a single-slice scan. The areas under the curves in (**a**) and (**b**) are equal. (**b**) demonstrates that the CTDI is equivalent to the absorbed dose measured from the radiation that would have only exposed regions given by ($-nT/2$, $nT/2$) but have exposed regions across locations in ($-z$, z)

The physical meaning of this area is the product of dose and length. When the area is divided by the X-ray beam width (nT), it results in an average dose of radiation that would have exposed only regions located in ($-nT/2$, $nT/2$) but had actually exposed regions in ($-z$, z). The average radiation dose within the X-ray beam width (nT) is illustrated in Fig. 10b, in which the area under the CTDI curve equals the area under the dose curve in Fig. 10a. The average radiation dose was calculated using the CTDI. Indeed, the CTDI represents the radiation dose that would have been measured when a series of contiguous irra-

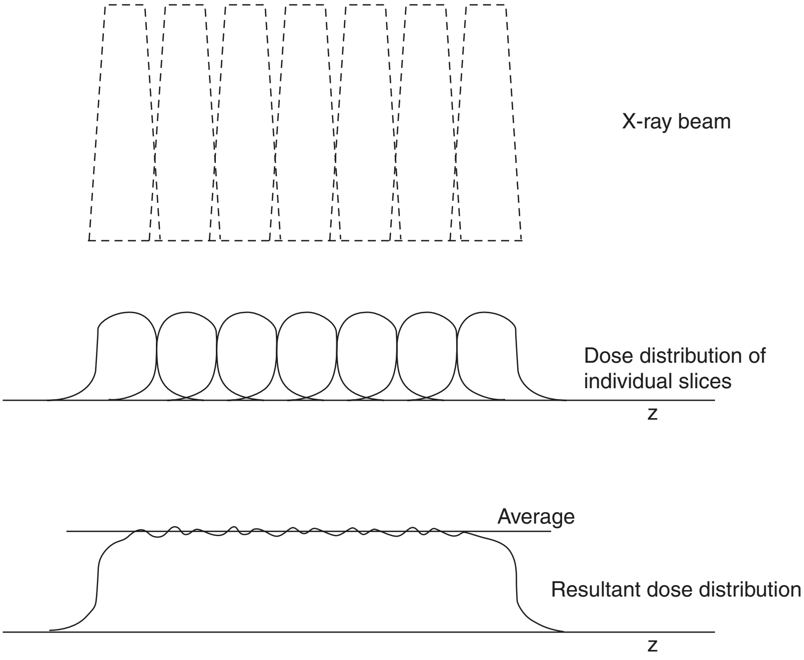

Fig. 11 Illustration of CT radiation dose profile of several contiguous scan slices. Each individual slice has a bell-shaped dose distribution (middle) along the *z*-axis. The resultant dose distribution along the *z*-axis over the range of the scanned slices is shown at the bottom

diations along the z-axis had been performed from −*z* to *z*, as illustrated in Fig. 11.

To determine the CTDI, the radiation was measured with a pencil dosimeter from one revolution of the gantry. As the active detection length of the dosimeter is longer than the collimated X-ray beam width (slice thickness), the radiation reaching the adjacent regions is also measured. The result of the measurement using a pencil dosimeter is a dose distribution over the *z*-direction of the scan, or dose versus length along the movement direction of the patient table. The dose distribution is integrated, and the result is then divided by the X-ray beam width (or slice thickness) to obtain an average absorbed dose, the CTDI. The CTDI is determined in the axial scan mode for a single gantry revolution to assess the radiation dose that would have resulted from a series of contiguous irradiations along the z-axis.

2.8 CTDI$_{\text{FDA}}$

CTDI does not standardize the width for the integration to include the radiation profile tails, which are illustrated in Figs. 8 and 11. For standardized dose measurements, Food and Drug Administration (FDA) of USA introduced a 14-nominal-slice width to determine the radiation dose, which was then denoted as CTDI$_{\text{FDA}}$. CTDI$_{\text{FDA}}$ is calculated using Eq. 6 and its unit is Gy. For the determination of CTDI$_{\text{FDA}}$, the standard scattering media for the head and torso phantoms are polymethylmethacrylate (PMMA) cylinders with a length of 14-cm cm and diameters of 16 and 32 cm for head and body examinations, respectively.

$$\text{CTDI}_{\text{FDA}} = \frac{1}{nT} \int_{-7T}^{7T} D(z)\,dz, \qquad (6)$$

where *n* is the number of slices acquired in a single gantry revolution (for single-slice scanners, $n = 1$; for multiple-slice scanners, n depends on the activated data channels used in the data acquisition with n equal to no. of active channels). In a single-slice scanner, *T* is the slice thickness, whereas in multiple-slice scanners, several detector elements may be grouped together to form one data channel and *T* is the width of one data channel.

2.9 CTDI$_{100}$

CTDI$_{\text{FDA}}$ also depends on the nominal slice width and tail of the radiation profiles. Potential variations in dose measurements owing to the scan-slice width are avoided using CTDI_{100}, which represents the average radiation dose at the central region of a 100-mm scan. The determination of CTDI_{100} requires that the radiation dose measurements extend 50 mm to each side of the scan location (Eq. 7). The data for determining CTDI_{100} was acquired using a 100-mm long, 3-cc active volume CT pencil ionization chamber and standard CTDI acrylic phantoms. The measurements were performed with a stationary couch.

$$\mathrm{CTDI}_{100} = \frac{1}{nT}\int_{-50}^{50} D(z)\,dz \tag{7}$$

where n is the number of slices acquired in a single gantry revolution (for single-slice scanners, $n = 1$; for multiple-slice scanners, n depends on the activated data channels used in the data acquisition with n = no. of active channels). T is measured in mm. In single-slice scanners, T is the slice thickness, whereas in multiple-slice scanners, T is the width of one data channel formed by detector elements grouped together.

2.10 CTDI_W

CTDI, $\mathrm{CTDI}_{\mathrm{FDA}}$, and CTDI_{100} represent the absorbed dose that would have been measured if contiguous scan slices along the z-axis were performed. They vary across the SFOV from the peripheral regions to central areas. To account for radiation dose variations in the SFOV, an average of CTDI_{100} is proposed estimating the absorbed dose across the SFOV. This quantity, denoted by CTDI_w, is calculated by Eq. (8). The values 1/3 and 2/3 approximate the relative areas represented by the center and peripheral regions, respectively.

$$\mathrm{CTDI}_\mathrm{w} = \frac{1}{3}\times \mathrm{CTDI}_{100,\mathrm{center}} + \frac{2}{3}\times \mathrm{CTDI}_{100,\mathrm{edge}} \tag{8}$$

where $\mathrm{CTDI}_{100,\mathrm{center}}$ and $\mathrm{CTDI}_{100,\mathrm{edge}}$ are the CTDI_{100} at the central and peripheral areas of the SFOV, respectively.

2.11 $\mathrm{CTDI}_\mathrm{vol}$

The determinations of CTDI, $\mathrm{CTDI}_{\mathrm{FDA}}$, CTDI_{100}, and CTDI_w are performed with a single gantry revolution. Clinical CT scan protocols often cover a range of anatomy and require multiple contiguous gantry rotations to complete data acquisition. The patient table moves a distance equal to, less than, or greater than the collimated X-ray beam width between the gantry rotations. A factor, known as the pitch, is used to describe the ratio of the table movement distance to the beam width. To account for the effect of pitch on the radiation dose, $\mathrm{CTDI}_\mathrm{vol}$, which is calculated using Eq. (9), was used.

$$\mathrm{CTDI}_\mathrm{vol} = \frac{1}{\mathrm{Pitch}}\times \mathrm{CTDI}_\mathrm{w} \tag{9}$$

where the pitch equals the distance moved by the table in a gantry rotation divided by the beam width. A pitch equal to 1 indicates the absence of a gap between adjacent slices while a pitch less than 1 means an overlap between adjacent slices, and therefore, more radiation exposure to the patient during the scan. A pitch greater than 1 indicates a gap between adjacent slices and hence, less radiation exposure to the patient but compromised image quality.

$\mathrm{CTDI}_\mathrm{vol}$ depends on both the peripheral and central CTDI_{100}, which neglects the scatter tails beyond 50 mm on each side of the scan slice. Consequently, this underestimates the equilibrium dose for body scan lengths of 250 mm or more by a factor of 0.6, on the central axis, by about 0.8, on the periphery, and by a factor of 0.7, for the dose-length product for all scan lengths (Boone 2007; Mori et al. 2005).

$\mathrm{CTDI}_\mathrm{vol}$ is a single CT dose parameter that can be measured directly and easily, and represents the average absorbed dose within the scan volume for a standardized phantom. $\mathrm{CTDI}_\mathrm{vol}$ represents the average absorbed dose over the x, y, and z directions for an imaging object whose attenuation is similar to that of the CTDI phantom. $\mathrm{CTDI}_\mathrm{vol}$ neither represents the average absorbed dose for objects of substantially different sizes, shapes, and attenuation, nor measures the total energy deposited in the scan volume as the scan length is not accounted for by the $\mathrm{CTDI}_{\mathrm{vol}}$.

2.12 Dose-Length Product

The overall energy deposition in the scan volume given by individual scan protocols can be accounted for by a multiplication factor, known as the scan length. The product of the scan length and $\mathrm{CTDI}_{\mathrm{vol}}$ is a better approximation to the total energy deposition in the scan volume and is known as the dose-length product (DLP) (Eq. 10), which has a unit Gy·cm.

$$\mathrm{DLP} = \mathrm{CTDI}_{\mathrm{vol}} \times \mathrm{scan\_length} \quad (10)$$

DLP indicates the total energy deposited in the scan volume and thus represents the potential biological effect of the examination. This is particularly useful; for example, an abdomen-only CT scan may have a $\mathrm{CTDI}_{\mathrm{vol}}$ equal to the $\mathrm{CTDI}_{\mathrm{vol}}$ of an abdomen and pelvis CT examination; the former would have a short scan length and hence a smaller DLP. The difference in these CT examinations shows that DLP is a better approximation of the potential biological effects than $\mathrm{CTDI}_{\mathrm{vol}}$.

Many contemporary CT scanners take advantage of helical scans, which require data interpolation between two points for all projection angles. Thus, the images at the beginning and end of the helical scan require data acquired beyond the planned scan locations, that is, the beginning and end of the anatomical range that are desired for the scan. This increases the actual scan length at the beginning and end of the helical scan. The increase in DLP owing to the necessary additional scan regions for data interpolation is known as “overranging.” In multiple-detector-row CT (MDCT) scanners, the additional scan length strongly depends on the pitch. A typical increase in the scan length is 1.5 times the width of the individual beam. The effect of overranging also depends on the length of the anatomical coverage; the shorter the coverage, the greater the effect.

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Patient Care and Self-Care in CT

Tristan Charles

Abstract

When exploring how we can best look after our patient's needs, we often neglect to look at the other side of the coin; our own needs as healthcare professionals. If someone is operating from a place of dissociation, anxiety, stress or burnout, they are not aptly equipped to meet the wide variety of needs of their patients. It is therefore necessary to explore both of these areas in parallel, as one complements the other. In this chapter, we explore the multifaceted layers of patient care, and what this looks like in a CT department. We discuss how to effectively inform a patient of the details involving their scan, and how to legally, ethically and efficiently obtain consent around radiation exposure and IV contrast. It is also important to understand that each individual patient has unique needs in a physical, mental and emotional sense. Learning how to meet the patient at their unique place, whilst at the same time efficiently managing the workflow of your CT department is an important balancing tool to have as a radiographer. We specifically touch on common scenarios seen in a CT department, such as trauma, oncology staging and anxious patients. Lastly, we explore areas of self-care for healthcare professionals and techniques to manage and improve outcomes on an individual and institutional basis.

Keywords

Patient care · Self-care · Health and well-being · Radiographers · CT scanning

1 Introduction

When it comes to caring for patients and staff in a CT department, there unfortunately is no "one size fits all" approach; each individual has their own specific needs and values. It is therefore necessary to find a balanced approach which optimises outcomes for both the patient and the healthcare workers on a case-by-case basis, as well as ensure the entire department operates in a safe and efficient manner.

This chapter explores the areas of patient care and self-care where this balance needs to be found.

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2 Clinical Considerations for Patients Undergoing a CT Examination

2.1 Obtaining Informed Consent

Informed consent in clinical practice can be used for two main purposes: first, as a legal covenant to protect the healthcare provider from reprisal in the chance of an adverse incident, and second to educate the patient around risks vs benefits of a medical procedure in order to improve autonomy in decision-making.

Obtaining consent from patients prior to a CT scan has extra complexity around adequately informing patients about the risks and benefits, because there is a large discrepancy between the available statistics and the actual risks. Ionising radiation, iodinated contrast media administration and interventional procedures all carry risk, however it is often difficult to present these risks to the patient in an unambiguous and accurate manner.

In this section, we will explore all three of these areas and discuss if informed consent is practical, and if so, what this would look like.

2.1.1 Ionising Radiation

Stochastic risk models from ionising radiation are still being debated amongst the international community. Although the linear no-threshold model has largely been implemented for the past few decades in a variety of contexts, there is no definitive evidence that doses less than 100 mSv are linked to increased cancer incidence or mortality (Cardarelli and Ulsh 2018, pp. 11). Also, stochastic risk is related to age and, to a lesser extent, gender, so it is not accurate to have a one-size-fits-all approach when discussing radiation risk with patients.

Informing patients of what is known and what is not known about radiation risk in an easy-to-understand way is important in improving patient autonomy (Brink and Goske 2012). Background Equivalent Radiation Time (BERT) is a useful tool to help patients understand radiation levels in diagnostic imaging compared to natural background radiation levels. On average in Australia, the yearly background radiation received is 1.5 mSv (ANSTO 2021). So if the dose from a diagnostic CT was estimated at 1.5 mSv, this would equate to 1 year BERT. This does not necessarily explain any possible risks associated with these doses, but it can help put the levels into context for the patient to make a more informed decision.

Due to the relatively low levels of radiation received in diagnostic CT, the ambiguous data and risk models, as well as the difficulty in simply explaining risk associated with radiation levels, formal written consent specific to ionising radiation is not necessarily required from patients prior to having a CT scan (Brink and Goske 2012). The reason behind this is that the majority of patients cannot give proper *informed* consent because they cannot be accurately informed of the relevant risks of radiation exposure from diagnostic imaging exams. The exemption to this may be for pregnant women receiving a CT scan, where the perceived risks to the foetus can be much higher.

2.1.2 Iodinated Contrast Media

Explaining the risks vs benefits of performing a CT scan with intravenous (IV) iodinated contrast media is an important part of obtaining informed consent from patients. IV administration of contrast is considered an invasive procedure and carries extra risk in regard to potential allergic reactions and contrast-induced nephropathy.

Since the advancement of non-ionic low-osmolarity contrast media, there has been a 5–10-fold reduction in mild to moderate reactions, compared to ionic high-osmolarity contrast (Royal Australian and New Zealand College of Radiologists (RANZCR) 2018). This statistically changes the risk vs benefits debate, however there is still a need to inform the patient of the chances of an adverse reaction.

Other factors to take into consideration when discussing risk vs benefits are the patient's age, renal function, medical history, and the requested scan and clinical query. Certain CT scans require IV contrast in order to answer the clinical query (for example, a CTPA to rule out pulmonary emboli), so the risk of not obtaining an accurate diagnosis may outweigh the risks associated with contrast media for these scenarios.

Ultimately, the patient has the right to refuse iodinated contrast media. If this is the case, the options presented to the patient would either be a non-contrast CT scan (if clinically valid), or alternative diagnostic tests. The accuracy of these alternative tests should be clearly discussed with the patient so that they can make an informed decision.

Presenting the patient with a written information sheet, paired with a relevant medical history questionnaire and a space for the patient to provide their written consent is advisable prior to administering iodinated contrast media.

2.1.3 CT-Guided Interventional Procedures

Therapeutic and diagnostic interventional procedures carried out under CT-guidance carry their own unique risks.

Radiation levels are generally low enough for routine procedures to not warrant too much concern, however CTDIvol can escalate to dangerous levels for complicated procedures.

Other risks include allergic reactions to medication, infection, infarction and physical injury such as nerve or joint damage.

Collating consistent, accurate statistics of these risks can be challenging for a number of reasons:

1. Some adverse events are very rare, so the numbers are considered to be statistically inaccurate
2. Individual experience and technique of the interventional radiologist play a big role in risk and outcomes
3. Many adverse statistics are obtained from interventional procedures carried out under other image-guidance procedures, such as fluoroscopy, which carry a greater risk compared to CT-guided procedures

That being said, the risks associated with interventional procedures under CT (however small they may be) can have serious consequences, so this needs to be clearly conveyed to the patient.

Presenting the patient with a written information sheet, paired with a relevant medical history questionnaire and a space for the patient to provide their written consent is advisable prior to CT-guided interventional procedures.

2.2 Preparation and Safety for CT Scans Requiring IV Contrast

2.2.1 Dietary Restriction

It is common practice to ensure a patient has nothing to eat prior to receiving IV contrast for their CT scan. The primary reason behind this is to minimise the risk and severity of the patient aspirating if they experience vomiting as a side-effect on the contrast injection. It also reduces the volume of bodily fluids expelled if a vomiting episode occurs, making cleaning and infection control measures easier for the staff. A secondary reason for food restriction is the improved visualisation of the stomach and small intestine lumen on the CT images, however this matter can be subjective depending on the reporting radiologist.

There is evidence that suggests dietary restriction offers no significant difference in adverse symptoms from IV contrast administration (namely nausea and vomiting) in patients compared to no dietary restriction (Barbosa et al. 2018). Consideration needs to be weighed for assuring safe, effective practice, and simplification and comfort for the patient. This may very well be patient-specific. For example, dietary restriction in diabetics poses extra risk compared to the rest of the population, so implementing conditional protocols for certain circumstances can result in reduced risk and improved outcomes.

The duration for dietary restriction can be variable between organisations, generally ranging from 2–6 h. Again, a balance needs to be achieved between image quality, workflow, and patient safety and comfort when deciding on the duration.

When explaining dietary restriction preparation to a patient, it is important to refrain from using the word "fast" or "fasting", as this implies the restriction of fluid intake as well. Having a patient that is well hydrated is important prior to and after IV contrast administration because:

1. It improves the success rate of cannulation.
2. It can reduce the risk of contrast-induced nephropathy, especially in moderate-to-high-risk patients (Cheungpasitporn et al. 2014).

2.2.2 Contrast-Induced Nephropathy (CIN)

Also called "Contrast-Induced Acute Kidney Injury", CIN is defined as a significant worsening of renal function as measured by an increase in serum creatinine levels of ≥25% following the administration of iodinated contrast media (Bartosz 2016).

It is recommended that all patients should be screened prior to contrast administration, and the following patients should be flagged as high-risk and a recent eGFR should be obtained (RANZCR 2018):

1. Known kidney disease (including transplant).
2. Diabetics.
3. Patients over 65 years old.

In regard to safe eGFR ranges for the use of iodinated contrast media, the following guidelines are recommended by the Royal Australian and New Zealand College of Radiologists (RANZCR):

1. **eGFR > 45 ml/min**: risk of CIN is non-existent. No special precautions pre- or post-administration is needed.
2. **eGFR 30–45 ml/min**: risk of CIN is very low to non-existent. Consider reduced contrast volume if possible. Oral hydration pre- and post-administration may be of benefit.
3. **eGFR < 30 ml/min (or actively deteriorating renal function)**: increased risk of CIN. Careful weighing of risks vs benefits of contrast administration should be undertaken, and alternative diagnostic tests considered. Periprocedural hydration and reduced contrast volume are recommended.

2.2.3 Hypersensitivity to IV Contrast

Allergic reaction to iodinated contrast media administered intravenously is classified as per Table 1 below (RANZCR 2018):

Some Key Points About Allergic Reactions (Cardarelli and Ulsh 2018)

- About 97% of reactions occur within 30 min of injection, with only about 3% of reactions having a delayed onset between 1 hour and 1 week.
- Delayed reactions are typically mild (rash) and not typically associated with broncho-

Table 1 Classification of allergic reactions to IV contrast media

Classification	Likelihood	Symptoms	Treatment
Mild	1–3%	Nausea, vomiting, pruritus (itching), urticaria (hives)	• Stop administration of contrast • Closely monitor patient • Non-sedating oral antihistamines
Moderate	0.04%	Marked urticaria, bronchospasm, laryngeal oedema, vasovagal attacks	• Stop administration of contrast • Call for help/ambulance • O2 via mask ± Ventolin • IM adrenaline (0.5 ml adults) • Lay flat and monitor vitals
Severe (anaphylactic)	0.001–0.04%[a]	Shock, respiratory/cardiac arrest, convulsions	As per above, plus: • Commence CPR if required • IV saline for hypotension • Airways management if required

[a] Risk of death from anaphylaxis is 0.001% or 1 in 100,000

spasm or laryngeal oedema. These are not necessarily medically urgent; however, patients should be advised to seek medical attention as a precaution.

- Non-ionic, low osmolar contrast is 5–10 times safer than ionic, high osmolar contrast. If a patient has had an allergic reaction to ionic contrast, then it is worthwhile weighing the risks vs. benefits of this patient receiving non-ionic contrast, since there is a possibility that a patient will not experience any adverse events.
- The likelihood of a reaction is 10 times higher in patients who have experienced previous hypersensitivity, however this depends on whether or not the contrast was ionic or non-ionic.
- Patients with asthma are 6 times more likely to experience hypersensitivity to contrast. The risk is related to the degree of control of their asthma symptoms.
- Patients with other allergies requiring medical treatment are 3–5 times more likely to experience mild contrast reactions.
- Shellfish allergy is not associated with increased risk of contrast media hypersensitivity (apart from the 3–5 times risk associated with other food allergies) (Bottinor et al. 2013).
- Topical iodine allergy is not associated with increased risk of contrast media hypersensitivity.

Premedication for Patients with Previous Allergic Reactions to Contrast

Premedication with corticosteroids ± H1 antihistamines (e.g. diphenhydramine) has been shown to decrease reaction rate in patients with previous history of hypersensitivity to iodinated contrast media to 0.5%, compared to 9.1% in patients who do not receive premedication (Greenberger and Patterson 1991).

For patients with a history of hypersensitivity, the best option is to consider alternative diagnostic tests, such as ultrasound, MRI, or CT without IV contrast. If it is decided that the benefits of CT with IV contrast outweigh the risk for a patient, then it is recommended to follow the premedication regimen below:

1. 50 mg prednisone orally 13 hour prior to contrast administration
2. 50 mg prednisone orally 7 hour prior to contrast administration (optional)
3. 50 mg prednisone orally 1 hour prior to contrast administration +/− 50 mg diphenhydramine orally.

2.2.4 Extravasation of Contrast Media

Extravasation occurs when contrast media is not delivered correctly into the intended vessel and instead leaks into the surrounding soft tissue.

Rates of extravasation are largely dependent on the skill and experience of the person inserting the cannula, as well as the due-diligence of the CT technician prior to injecting the contrast.

Below are some tips to reduce the chance and/or severity of contrast extravasation:

- Remain in close proximity to the patient and injector for at least the first 5–10 seconds during contrast administration in order to monitor the injection site for signs of extravasation. If this is not possible due to protocol time restrictions, consider using a timing bolus method with 10–15 ml contrast to “test” the efficacy of the cannula.
- Warm contrast to 38°C prior to administration.
- Use a slower flow rate if the efficacy of the cannula is suspected to be compromised, or if a narrow-gauged cannula is used.
- Ensure the cannula is not kinked in-situ during contrast administration. If the cannula is placed in the patient’s cubital fossa, then ensure their elbow remains straightened throughout administration of contrast.
- Always flush the cannula before connecting to the contrast injector.

If contrast extravasation occurs, the following management protocols should be followed:

1. Stop contrast injection as soon as possible, and make note of approximate volume extravasated into tissue.
2. Remove cannula.
3. Conservative management for patient comfort, such as limb elevation, and alternating hot/cold compression, until pain and swelling subsides.
4. Inform the patient about signs and risks of compartment syndrome, and the need to seek urgent medical attention if it occurs. This includes:
    (a) Increasing pain.
    (b) Tingling or burning sensation.
    (c) Loss of sensation, especially distally to extravasation site.

2.2.5 Pregnancy and Breastfeeding in Relation to Iodine Contrast

Pregnancy

There are no studies to date that have linked iodinated contrast administration during pregnancy to foetal injury, malformations or adverse events. There has been concern about the uptake of iodine in the foetus' thyroid, as free iodine in the contrast solution is easily permeable through the placenta. However, of the limited retrospective studies there have been no links to contrast and abnormal thyroid function in the infant at birth (Tremblay et al. 2012).

Due to the limited data available, as a precaution, it is recommended that pregnant patients only receive iodinated contrast if

1. There are no other alternative diagnostic tests (radiation exposure also needs be taken into consideration).
2. The information obtained from the scan is of benefit to both mother and child.
3. The scan cannot be delayed until postpartum.
4. The infant obtains a thyroid function test at 1 week postpartum.

Breastfeeding

Studies have shown that the amount of iodine excreted in breastmilk over a 24-hour period post-iodinated contrast administration is 0.5% of the original maternal dose. Less than 1% of the iodine excreted in breastmilk will be absorbed by the infant if ingested (Nielsen et al. 1987). That is, if 100 ml of contrast has been administered to a breastfeeding patient, less than 0.005 ml of this may be absorbed by the infant. This can be considered negligible.

Therefore breastfeeding mothers should be told that cessation of breastfeeding or discarding of breastmilk is not necessary after receiving iodinated contrast, and the benefits to the child and mother of continuation of breastfeeding far outweigh any risks associated with contrast excretion.

3 Patient Interaction and Communication

3.1 Values & Biases in Patient Interaction

Cambridge Dictionary defines bias as: "the action of supporting or opposing a particular person or thing in an unfair way, because of allowing personal opinions to influence your judgment". Evidence shows that bias behaviour is often carried out on a subconscious level, meaning the individual may not even realise they are behaving in a biased way (Byrne and Tanesini 2015).

3.1.1 Values & Biases of the Healthcare Professional

It is a healthcare professionals' duty to provide equal and unbiased care to their patients, regardless of race, gender, age, social status or any other area that potentially creates division.

When an individual is presented with a situation which clashes with their own personal values and opinions, they are more likely to act in a biased manner. Therefore, understanding personal values and opinions is key to avoiding biased behaviour. These usually are expressed in the form of the statement: "X is always Y", where

"X" is a certain demographic and "Y" is a particular action or trait. The key problem with this statement is the word "*always*". Very few things can be said to *always* occur, so bringing awareness to statements like this is the first step to understanding when an individual may be acting out of bias.

Here is an example:

> "ALL patients who live in the far end of town (X) are ALWAYS rude and violent (Y)".

While there may be a statistical increase in this behaviour amongst this demographic, it is biased to say that *ALL* patients in this demographic will *ALWAYS* act in this way. This type of statement can also result in *confirmation bias*, where an individual subconsciously only remembers events where this statement was proven to be true, but fails to remember other events where people from this demographic were *not* rude and violent.

Believing such statements can result in a change in behaviour and attitude of the healthcare professional toward individual patients, which can have an impact on the level of care the patient receives, and their outcomes (FitzGerald and Hurst 2017). It is therefore important to ensure that each individual patient is treated on "face value". That is, the level of care should be adapted to each individual patient's needs and situation, regardless of their demographics and background. It also means that if a patient is acting in a certain way (regardless if it confirms a biased opinion or not), then the level of care should be adapted to respond to this behaviour, whilst ensuring safety and respect for everyone involved.

3.1.2 Values & Biases of the Patient

Similarly to how personal values and biases can influence the behaviour of a healthcare professional, each patient will present with their own values and biases which will influence their behaviour. These values and biases are often formed from a patient's past experience in a healthcare system, either directly or witnessed, and can be a mix of positive and negative.

If a patient has received or witnessed bias care from healthcare professionals in the past due to factors that are largely out of their control (e.g. race, gender, religion, socioeconomic status), then they will more likely behave in a manner that can appear as rude, uncooperative or even aggressive toward other healthcare professionals. In the limited time a patient spends in the CT department, it is not possible to truly empathise with a patient in order to understand their past experiences and resulting biases; however, the CT technologist has a choice in how they respond to certain behaviours:

1. They can let their own biases confirm their opinion about a particular demographic that a patient represents, and respond with a similar mannerism;
2. They can play the victim (e.g. this patient does not like ME), and respond defensively or even aggressively; or
3. They can apply a level of empathy and try to understand the patient's *perspective*, and respond in a balanced way that meets the patient at their unique position, whilst maintaining integrity and respect for their own wellbeing and safety.

The third option is not always the easiest to achieve, as it requires the technologist to put their own ego aside for the greater good of the patient's outcomes. However if the situation is handled with respect and care, it can be a transformative experience for all parties involved, and may even resolve a level of bias for each individual going forward.

3.2 Language and Communication

Taking a patient-centred approach with technologist-patient communication leads to improved patient outcomes and satisfaction (Itri 2015). *Itri* proposes an acronym-based communication model that can assist technologists, *AIDET*.

- **Acknowledge—**when greeting the patient, acknowledge any unique or specific circumstances regarding their visit (e.g. apologise if running late, address any concerns or questions they might have, identify any areas of special needs that may require extra or different care).

- **Introduce—**state your name and role.
- **Duration—**provide a timeframe for the examination.
- **Explanation—**explain what will happen during the examination, what the patient may experience, relevant risks and benefits (indications) of the examination, and provide the opportunity for any questions.
- **Thank you—**thank the patient for their cooperation.

The above model can be used as a framework when communicating to a patient, however it is important to be flexible with the flow of an interaction with a patient. The most important factors from a patient-experience perspective include acknowledgement of a patient's concerns, being treated with respect, and being treated like a person (Steele et al. 2015). If a patient perceives that their technologist is simply ticking off a list of things to address in order to meet their minimum due-diligence, then all three of the above factors will be impeded. Rather, an open dialogue between technologist and patient is required for both patient safety and satisfaction.

3.2.1 Language Barriers

If the technologist and the patient do not speak the same language, it is necessary to ensure an interpreter is available to translate any necessary instructions, preparation and medical questions before undergoing their scan (except in the event of an emergency). It is ideal to enlist the service of either a professional medical interpreter or a member of staff who speaks the language, however this is not always available. A patient's family member, friends or a member of the public are all options for interpretation, however these come with added medico-legal risk. Each organisation will have their own policy on this which needs to be followed.

Providing translated information and consent forms has become an accreditation requirement in some regions and is a relatively inexpensive and effective way to ensure the majority of patients are informed and safe.

Most CT scanners will have multiple languages available for patient instructions in the scanning protocols. If the required language is not available, most scanners also have the capability to record verbal instructions. It can be useful to hire a professional medical interpreter to record a range of patient instructions on the scanner for later use.

3.3 Patient Greeting

Use the initial interaction with a patient to address the following:

1. Introduce yourself and your role
2. Patient identity check—name, date of birth and address
3. Paperwork check—referral, medical history and consent forms, previous reports, pathology, etc.
4. Check for any special needs or requirements that the patient may have—this initial stage of the patient's visit can dictate the quality and outcomes for all subsequent stages, so it is important to remain extra vigilant for any specific needs of the patient, and to address any questions or concerns with respect and care

3.4 Patients with Specific Needs

3.4.1 Anxiety

Anxiety can have a variety of causes and manifest in a variety of ways for each patient:

Causes

- Claustrophobia
- Needle-phobia
- "Scanxiety"—anxious about the results of the scan
- Previous trauma or sexual assault

Signs & Symptoms

- Stiff and rigid body language
- Short, abrupt communication (this may seem like the patient is being rude or aggressive)

- Introspective and quiet
- Shallow, rapid breathing
- Sweating

The most important thing a technologist can do when caring for patients with anxiety is to make them feel safe and in control of the situation. Try to actively listen to what the patient has to say, even if it may seem irrational. The patient needs to know that the people caring for them are "on their side". Simply telling a patient "don't worry" or "you'll be fine" when they are anxious about their scan will not be effective, and may even elevate their anxiety levels even further, as they may feel as though they are not being listened to.

Giving the patient options, rather than telling them they must do something, can also give them a level of control of the situation. This can even be around having the scan itself; except for extreme circumstances, a patient cannot be forced to have a CT scan against their will, so reiterating this to the patient can help to relieve anxiety. Interventions such as IV contrast should also be presented to the patient as an option that they can refuse, however the risks vs benefits of their choice need to be clearly articulated to the patient.

Finally, it is the healthcare professional's responsibility to not pass judgement onto patients. It is impossible to truly empathise with a patient in regard to what is causing their anxiety and how they are feeling, therefore it is not a place to judge. How the technologist chooses to interact with the patient has a significant influence on either lowering or elevating their anxiety levels, and this can change the outcomes of their examination and treatment.

3.4.2 Physical Limitations/Disabilities

When caring for patients with physical limitations or disabilities, ensure the physical safety of both the staff and the patient. Practicing safe manual handling techniques when transferring patients on and off the CT table can include:

1. Establish a safe CT table height—this is generally hip height of the average staff member
2. Ensure brakes are applied to the patient transport device before moving the patient
3. Avoid twisting motion when supporting the patient's weight
4. Ensure adequate number of staff to minimise strain
5. Use transfer equipment when available/needed

Sometimes it is necessary to adjust the CT scanning protocol or method to accommodate a patient's ability. This can include:

- Placing the patient in a different position, including position of their arms—if arms are placed in the region being scanned, ensure the exposure factors are adjusted accordingly
- Reducing the duration of respiratory instructions—by increasing tube rotation speed, pitch and/or beam collimation
- Remove or displace any externally attached medical equipment from the region of scan

3.4.3 Children

The interaction and management of children in CT are quite similar to that of patients with high levels of anxiety, as outlined previously. Some key points to improving the success rate of CT scans on children include:

- Keep formal instructions to a minimum—do not overwhelm the patient with unnecessary information or instructions. Any medico-legal discussions should be directed to the child's carer, ideally away from the patient.
- Maintain a light, colloquial mannerism.
- Find a balance between letting the patient direct the pace and progression of the examination, while not allowing for too many delays. The less time the patient is on the table, the less likely they will experience stress and anxiety, however rushing through the exam may also elevate stress and anxiety.
- Allow the child's parents or carers to stay in the CT room with the child for as long as possible. Avoid having any unnecessary people in the room during radiation exposure. If this is unavoidable, ensure these people wear the

appropriate radiation protection equipment and stand as far away from the gantry opening as possible.

3.4.4 Aggressive & Intoxicated Patients

Ensuring the physical, psychological and emotional well-being of the CT department staff is the number one priority when dealing with aggressive or intoxicated patients. Below are some methods to help achieve this:

- Do not allow a staff member to be alone with high-risk patients.
- Maintain physical distance where possible.
- Do not engage in the patient's rhetoric—arguing, disagreeing with or judging the patient can exacerbate the situation.
- Apply a reasonable level of empathy towards the patient's situation—understanding that aggressive behaviour can be an effect of numerous causes, sometimes out of the patient's own control or awareness, can allow the staff member to empathise with the patient.

3.5 Medical History & Referral Review

When reviewing a patient's CT referral, there is some key information that must be checked prior to performing the examination:

1. Patient's details—name, date of birth, address, etc.
2. Type of scan—ensure it does in fact state "CT", and if there are any specific requests such as "angiogram", "multiphase", "non contrast", etc.
3. Region of scan—chest, abdomen, brain, etc.
4. Clinical history and indication—ensure the requested scan is the most suitable for demonstrating the clinical question.
5. Referrer's details and signature—a signature is a medico-legal requirement in most regions.
6. Date of referral—ensure the referral has not expired, subject to regional requirements.

Depending on the requested exam and clinical history, there may be a need to obtain a more thorough medical history. This can be used to obtain a more accurate diagnosis, as well as improve patient safety.

3.5.1 Common Medical Questions for IV Contrast Administration Include

- Previous exposure to iodinated contrast media.
- History of allergies.
- Other medical conditions—asthma, diabetes, thyroid dysfunction, renal impairment, pregnancy, breastfeeding.

3.5.2 Common Medical Questions for Interventional Procedures

- Current medications, including anticoagulants.
- History of allergies.
- Patient transport arrangements (required for nerve blocks and epidural injections).

4 Navigating the CT Department as a Technologist

4.1 Alignment of Values between the Healthcare Professional and the Healthcare Institution

Earlier in the chapter we discussed how values and biases can impact on the level of patient care provided. Similarly, a mismatch of values between the individual worker and an organisation/department can lead to conflict, lack of productivity and a reduction in overall patient care and safety.

Understanding one's own values is the first step in determining if there will be an alignment or conflict in the values of the organisation or department that they work in. Values can be divided into two categories:

1. Negotiable values—these are the values that are important to an individual or organisation,

but can be compromised in certain scenarios, depending on the context and outcomes.

2. Non-negotiable (core) values—these values are absolute for an individual or organisation, and generally cannot be compromised.

When there appears to be a conflict in values in a workplace, identifying if these values are negotiable or non-negotiable is the first step towards any sort of resolution. It is possible to have a happy and productive work environment, even when there is a conflict of negotiable values. Exploring if there is some level of compromise between the individual and/or organisation may be enough to satisfy both parties. However, if there is a conflict of non-negotiable values in a workplace, a resolution may not be possible, and may result in adverse outcomes for the individual, the organisation and their patients if the current trajectory is allowed to continue.

4.2 Roles, Responsibilities & Goals for CT Technologists

Every workplace should have an explicit list of the roles and responsibilities for CT technologists. These can include, but not limited to:

- Responsible for the safety and well-being of patients from the start of preparation, scanning and afterwards (until the time of any possible delayed adverse events has passed).
- Obtain diagnostic images that answer the clinical question, at the highest possible image quality and the lowest possible radiation dose.
- Flag potential “red flag” or urgent pathologies with the radiologist.
- Ensure all medications, consumables and accessories are stocked and within their use-by date in the department.
- Maintain relevant training and ongoing education.

Individual radiographers may choose to list their own roles and responsibilities that do not necessarily fall within the industry or organisational policies. Some examples can include:

- Provide unbiased, compassionate care to all patients.
- Refine and improve CT protocols to optimise image quality and radiation dose.
- Provide extra support to patients with special needs.

These examples can also be closely tied with personal and professional goals. Setting goals can be a beneficial practice for improving job satisfaction, productivity and motivation, as well as limiting burnout and other job-related ailments (Locke and Latham 1991). Goals provide a framework for how to act and where to focus energy and attention. Achieving goals provides a sense of achievement and value, that often cannot be obtained with the traditional remuneration frameworks in a workplace.

4.3 Balancing Workflow in a CT Department

4.3.1 Trilemma of CT Workflow

Working in a busy CT department requires a tight balancing act, but ultimately there will always be certain areas that need to be “sacrificed” in favour of others. When looking at CT department workflow, there are three main factors that need to be balanced, with *time* being the overarching constant:

1. Quality—producing high quality images with minimal mistakes.
2. Quantity—completing a high number of examinations.
3. Patient care—ensuring patient’s needs are met so they are comfortable and safe.

In a set time frame, without an increase in resources, it is impossible to favour all three of these factors. This can sometimes be referred to as a *trilemma* (triangle dilemma) (Fig. 1).

1. If the focus was shifted towards patient care/comfort/safety and quality, then the potential number of examinations performed would decrease.

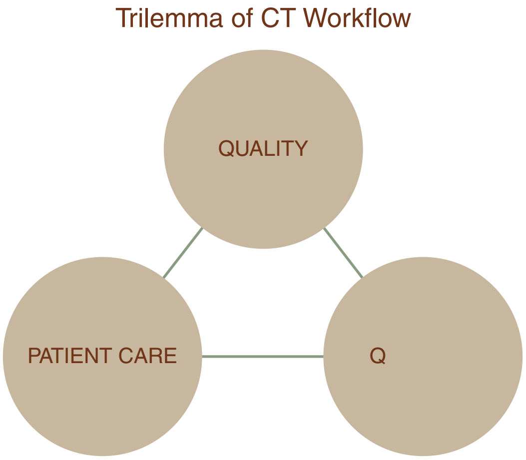

Fig. 1 Trilemma of CT workflow

2. If the focus was shifted towards quality and quantity, then there would be less time and resources to focus on patient care.
3. Finally, if the focus was shifted towards patient care and quantity, then the quality of work may suffer.

Unfortunately there is no percentage or number that dictates what an appropriate balance would be. The CT department workflow needs to respond and adapt to the resources and requirements in each moment, for each patient. The *work* needs to *flow* between all three factors to reach the most practical and desirable outcome for everyone—the patient, staff and department.

- For a full patient list that is running behind, quantity may need to be favoured more-so in order to minimise waiting times and delays in results.
- If there are patients with special needs or requirements, then it may be acceptable to reduce the number of scans being performed and run behind on the worklist.
- If the experience and skill level of the staff are low, then focussing on quality may be necessary in order to minimise errors.

4.3.2 Empathy vs Sympathy

Healthcare professionals are often taught to be empathetic towards their patients, not sympathetic. However this statement alone can lead to confusion regarding how to act and feel in a clinical setting, especially since there is a common interchangeable misuse of these words (Jeffrey 2016).

Empathy is the ability to understand or imagine another person's experience, feelings or psychological state (Neukrug 2017). Empathy does not necessarily involve any actions to intervene or relieve the other person's suffering, but may involve the observer communicating their understanding of the situation to the individual.

Sympathy is closely linked to compassion, and is when the observer experiences *concern* for another person's experience, feelings or psychological state. Sympathy is often attached to the observer's own emotions and reactions, and the desire to relieve someone else's suffering may arise from egoistic motivation to relieve one's own distress (Jeffrey 2016).

It is therefore important for the healthcare professional to understand their own experience, feelings or psychological state in the context of patient care, in order to determine the most appropriate way to act in a situation. This understanding provides a framework for the individual's emotional and professional *availability* to provide care. This also needs to be factored in with their *ability* (both personally and professionally) to provide relevant care, as well as the *resources and protocols* within the institution they are working in to accommodate for such care. This relationship is displayed in Fig. 2 below:

For optimum workflow in the CT Department, a balance needs to be found between the above factors. Regardless of how much ability and availability an individual healthcare professional has for providing patient care, the optimal level will not be reached if the institution does not provide sufficient resources or relevant protocols to allow for this care to be provided, and vice versa.

4.3.3 Patient-Centred Care

The concept behind patient-centred care states that each individual patient has their own unique needs and values, and that decisions regarding

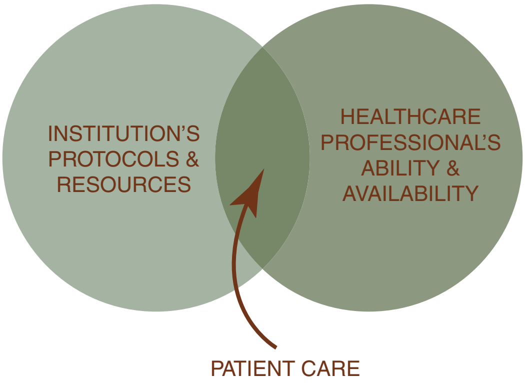

Fig. 2 Patient care—each individual healthcare professional's ability and availability to provide care to patients is unique. The amount of care a patient receives is also dependent on the resources and protocols of the institution that the healthcare professional works within

their health need to be a collaborative discussion between the patient and their healthcare provider (Delaney 2017).

Including individual patient needs and values into the above model of patient care adds an extra layer of complexity and a smaller "target" to achieve optimum balance in CT department workflow (see Fig. 3 below); however, outcomes for both patient and institution will improve as a result (Itri 2015).

Effective communication, patient education, physical and emotional support, and respect of the patient's autonomy, values and preferences are all key factors in ensuring patient-centred care in a CT Department (Itri 2015).

5 Self-Care as a CT Radiographer

When exploring how to best look after a patient's needs, the needs of the healthcare professional are often overlooked. If an individual is operating from a place of dissociation, anxiety, stress or burnout, they are less likely to meet the wide variety of needs of their patients. Therefore, it is essential to address sustainable and healthy work and lifestyle practices for CT technicians in order to achieve a high standard of care for their patients.

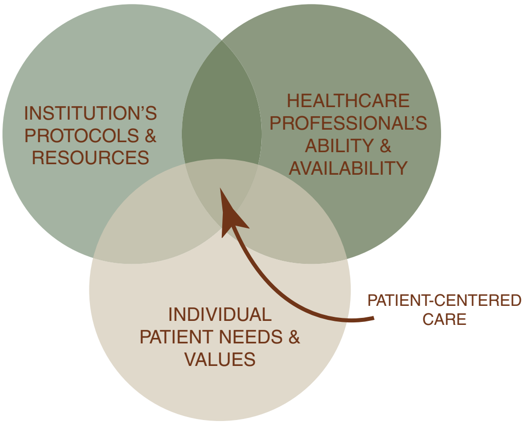

Fig. 3 Patient-centred care

5.1 Healthy Lifestyle and Work Habits

A healthy lifestyle can be difficult to establish, but it is easier to maintain once it becomes part of a routine/habit. Working in a busy CT department can take its toll on the staff's physical, mental and emotional health, but there are practices that each individual can put into place to minimise the health impacts of their work environment.

5.1.1 Scheduled Breaks

Every organisation and industry will have laws and policies around maximum working hours and minimum break times for its workers. While the duration of a break can influence the sustainability of a workplace, the *quality* of an individual's break can have a far more meaningful impact. Below are some tips for utilising work breaks for maximum benefit:

1. Spend time outside—many CT workspaces have little-to-no natural light, so ensuring at least some part of the day is spent outside can help boost vitamin D and mood.
2. Minimise screen time—working in CT results in high amounts of screen time, which has been linked to reduced quality of sleep and other health impacts (Feng et al.). Use the scheduled breaks to have a rest from screens and readjust the eyes.
3. Eat healthy, nutritious food and drink water.

5.1.2 Breath and Body Awareness

Becoming aware of breathing patterns, muscle tension and overall body posture throughout the day are useful habits that can immediately improve physical and mental states, as well as reduce chronic health conditions.

During times of high stress or pressure, there is a tendency to inhale shallowly and/or through the mouth, which has been linked to numerous physical and mental health conditions (Nestor 2020). Forming a habit of becoming aware of breath patterns throughout the day can interrupt the cycle of incorrect or poor breathing techniques.

Similarly, becoming aware of poor posture and repetitive or sustained areas of tension of the body, especially during times of stress, can help prevent repetitive strain injuries and muscle soreness.

Creating a workspace that promotes good posture can help prevent repetitive strain injuries. Setting the bench at a height so that the CT monitors are at eye level whilst standing will prevent slouching and also reduce the amount of sedentary time, which has been linked to deleterious health outcomes (Biswas et al. 2015).

5.1.3 Mindfulness and Other Self-Care Tools

When an individual is mindful, they are aware of their thoughts in the *present moment* (i.e. their thoughts are not taking them back to the past or projecting them into the future). This present moment awareness provides a foundation for creating more positive and efficient thoughts and actions going forward. It can help prevent someone from unconsciously falling into a mental or habitual routine that can often be self-destructive and have a negative impact on others. Mindfulness has been shown to reduce anxiety, depression and stress (Khoury et al. 2013), as well as improve the overall well-being of seemingly “healthy” individuals.

There is no tangible goal with being mindful; it is a conscious mindset that requires continuous awareness and adjustment. However like most things, it improves with practice.

The key to mindfulness is to find what works for each individual—different tools and schedules may work better or worse for different individuals, depending on their unique circumstances, personality, attitude and motivation. There are a variety of tools that can be used to achieve a mindful state, such as journaling, creative work, physical exercise, meditation and breathwork, but ultimately these practices need to be performed with appropriate intention and awareness in order to achieve the best outcomes.

Journaling

Writing in a journal can result in a variety of benefits, such as identifying, expressing and regulating feelings and emotions more effectively, improving cognitive function and decision-making ability, and improved self-awareness, reflection and insights. It has been proven to increase compassion satisfaction, and reduce compassion fatigue and burnout in healthcare professionals (Dimitroff et al. 2016).

Physical Exercise

Certain roles within a CT department can be favourable for preventing sedentary behaviour amongst staff (due to activities such as patient transport and escorting, walking in and out of the scanning room); however, other roles such as scanning and post processing can increase sedentary behaviour. This, coupled with high screen time, can be attributed to a decrease in physical and mental well-being in CT staff (Feng et al. 2014).

Maintaining a regular physical activity schedule both inside and outside of work can lead to a wide range of physical and mental health improvements. Activities outside of work are the responsibility of the individual, and dependent on their unique circumstances, however steps can be taken to improve physical activity inside the workplace:

1. Establish a standing workspace at the CT scanner and/or post-processing area.
2. Promote role-rotation amongst staff to encourage a wider range of physical movements.

3. Encourage staff to take a walk during their scheduled breaks.
4. Organise a social sport team amongst work colleagues.

Meditation and Breathwork

Meditation and breathwork are closely linked practices that help improve mindfulness and awareness of the subconscious cycles that often influence an individual's thoughts and actions in day-to-day life. They can also be used to regain composure throughout the day, release built-up stress, tension and emotions, process past traumas, and ultimately realise one's own potential, purpose and place in life.

There is no specific training or pre-requisite to be able to practice and benefit from meditation and breathwork, and they can be practiced anytime and in a variety of settings. Below are some practical techniques that can be used during and outside of work for CT technicians:

1. *Breath Awareness:* Become aware of your breath during times of stress and pressure, for example when caring for a trauma patient. If you notice your breath has become shallow, through the mouth or if you are holding your breath; consciously take a deep, active inhale through the nose and then gradually let the exhale out as a "shhhh" sound through the mouth (the sound is optional). Repeat as many times as necessary.
2. *Conscious Connected Breath:* Find a quiet space to sit or lay comfortably with your eyes closed. Start taking active continuous, connected breaths through an open mouth, so that there is no pause between the inhale and exhale, or the exhale and inhale. Continue this breathing pattern for 5, 10 or 15 min (or longer), staying aware of whatever sensations or experiences arise without trying to control the process—just keep breathing. This technique is valuable as a daily practice to reduce stress, regulate emotions and become more grounded and present. It can be especially useful to process and integrate traumatic experiences (either direct or witnessed) on a subconscious level—something healthcare professionals are exposed to on a regular basis.
3. *Box Breathing:* Breathing through the nose, inhale for 5 s, hold for 5 s, exhale for 5 s, hold for 5 s. Repeat this cycle for as long as required or comfortable. The duration of each phase can be increased or decreased as preferred (e.g. 4, 4, 4, 4 s; or 6, 6, 6, 6 s; etc.). This can be applied almost anywhere in your day-to-day settings, and can be used to calm the nervous system, focus on a task and achieve increased sustained performance during physical exertion.

5.1.4 Managing Stressful or Traumatic Situations in a CT Department

CT department staff are prone to being exposed to stressful or traumatic events, regardless of whether they work in a public hospital or private practice. This can include:

- Scanning patients who have experienced severe physical trauma/injury.
- Patients passing away on the CT table.
- Patients experiencing an allergic reaction to IV contrast.
- Detecting a serious disease on a patient's scan.
- Witnessing the deterioration of a patient's health on subsequent follow-up scans.

Minimising exposure to such events is not always practical, so learning how to manage and process these events when they do occur is a more realistic approach to self-care for CT technicians.

When witnessing a stressful or traumatic event, the individual can respond on a variety of levels:

- Mental—cognitive understanding that the event was distressing. The individual may try to create a mental narrative around the event, such as a step-by-step rundown of the different individual components or aspects to the event. Cognitive dissonance can be a delayed response, where the individual has a frag-

mented memory of the events and often dismisses the event as insignificant.
- Physical—experiencing a visceral reaction, such as nausea, trembling, hot/cold sensations, increased respiratory and heart rate, etc. These are often linked with an activated sympathetic nervous system (fight, flight or freeze).
- Emotional—for example, sadness, fear, grief, anger, etc.

The first step to processing a traumatic event is for the individual to *acknowledge* how it made them *feel*. By "pretending" the event did not have an impact on their mental, physical or emotional state, the individual is likely to remain in an activated sympathetic nervous system state, potentially resulting in a cascade of short- and long-term implications. If the individual is exposed to any subsequent traumatic events without adequately processing previous events, then the likelihood of cognitive dissonance increases and the post-traumatic symptoms may solidify or worsen (Levine and Frederick 1997).

The next step is prioritising the time and resources for CT technicians to debrief and process their witnessed traumatic events. There are a variety of tools and resources available to CT technicians, including (but not limited to):

1. Counselling or talk therapy.
2. Debriefing with colleagues.
3. Taking a 5 min break after an event to recompose and decompress.
4. Self-care practices such as journaling, physical exercise, meditation and breathwork, etc. (as discussed previously).

It is worth noting that successful processing of traumatic events is often carried out on a subconscious level, which helps to regulate the autonomic nervous system and complete any emotional response that may have been interrupted. That is, an individual cannot always *think or talk* themselves out of a trauma response, but rather they must *feel and experience* their way through it (Levine and Frederick 1997).

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Part II

CT in an Emergency Setting

CT in an Emergency Setting

Lindiwe Gumede and Nicole Badriparsad

Abstract

Computed tomography (CT) has become a central component in the imaging of both traumatic brain injury (TBI) and non-traumatic brain injury (nTBI) patients as it provides a key role in patient triage and management. Radiographers play a crucial role during imaging and must maintain an ongoing responsibility to ensure radiation safety during all CT procedures. However, CT imaging protocols used in TBI and nTBI patients remain unstandardized and may vary from department to department. Consequently, imaging techniques play an integral role in the diagnosis and management of patients presenting with TBI and nTBI and may influence life or death decisions. This chapter presents CT imaging techniques which include imaging algorithms and indications, CT protocols, and management of radiation dosages in the imaging of TBI and nTBI patients. This chapter aims to present examples of a few of many variations in current practice and to recommend what could be adopted to be standard protocols.

Keywords

Traumatic brain injury · Computed tomography · Emergency · Protocols

1 Introduction

CT is used worldwide to diagnose neurologic emergencies, such as acute TBI, nTBI (stroke), and aneurysmal hemorrhage (Kuo et al. 2019). For this chapter, a CT emergency is regarded as the setting in the radiology department that must aim to reduce the mortality rate in patients presenting with traumatic brain injury (TBI) and non-traumatic brain injury (nTBI). It is important to note that most TBIs are the result of road traffic accidents, assault, falls, penetrating injuries, and others (Gitto et al. 2015). Depending on the specific history and the clinical presentation of the TBI and nTBI, most of these patients are referred for CT trauma brain (Ringl et al. 2010). This is since CT is usually the modality of choice for TBI and nTBI as it is fast and cost-effective. In support Lolli et al. (2016), Koegel et al. (2018) state that CT is the most frequently used as an initial examination for imaging of TBI and nTBI. CT is also considered the “gold standard”

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for detection of acute hemorrhages (Hemphill et al. 2015; Morgenstern et al. 2010; Vilela and Wiesmann 2020).

TBI is a vital condition that has a noteworthy global impact (Charry et al. 2017). For this chapter, trauma will be defined as either deliberate or non-deliberate, while extensive trauma will be defined as an injury that needs further intensive attention and occasionally surgery (Hardcastle et al. 2016). Despite being common knowledge, radiographers are not responsible for reporting CT images; however, it is important to acknowledge pattern changes to alert the radiologists soonest (Etheredge 2011; Hlongwane and Pitcher 2013). This may facilitate a quicker awareness on the radiologists' side especially in cases of outpatients presenting with nTBI. It is rather important to note that the diagnoses of intracranial hemorrhage, contusion, and traumatic infarction represent the most important clinical questions that CT imaging can assist with solving and that the correct diagnosis of fractures is next in importance (Ringl et al. 2010). Protocols vary from one department to another and therefore below are illustrations of common protocol considerations which are usually changed according to the radiologist's preference or patient condition in a specific department. However, for most protocols concerning structural imaging of the brain and skull base, a non-contrast CT (NCCT) is usually adequate (Romans 2011).

2 Traumatic brain injury

TBI is the most common cause of death after trauma. The primary cause of TBI varies according to the patient's age (Kim and Gean 2011). In general, pediatric patients and geriatric patients are prone to accidental falls, while young adults and adults are more prone to vehicle accidents and assaults (Gerritsen et al. 2018). Therefore, medical practitioners carry the responsibility to differentiate between minor and serious TBI (Gerritsen et al. 2018). It is deemed common that TBI is regarded as the highest contributor to workloads in emergency medical departments (Nayebaghayee and Afsharian 2020). Additionally that patients with TBI have noteworthy CT findings requiring neurological intervention (Singata and Candy 2018).

Regarding neurological intervention, the Glasgow Coma Scale (GCS) is considered as the scoring system used to score the acuteness of the TBI and can offer a broad framework for clinical grading by assessment of verbal, visual, and motor components ranging from 3 to 15 (Whitnall et al. 2006; Jalali and Rezaei 2014). Therefore, classifying TBIs considers the lowest GCS in the first 48 hours and therefore serves as a useful triage tool to ascertain the need for CT (Haaga and Boll 2017: p.430). However, in practice even when the GCS score is normal, the CT results may be positive. TBI imaging in the emergency setting is done to avoid possible secondary neurologic damage from developing from the primary brain injury (Besenski 2002). NCCT is important for triage in imaging of TBIs and follow-up of patients with primary TBI symptoms because it is quick to diagnose TBI and is available in most hospitals (Schweitzer et al. 2019; Figueira Rodrigues Vieira and Guedes Correa 2020).

Indications for imaging can be divided into considerable risk, moderate risk, and minimal risk groups (Besenski 2002) *as seen below in* Table 1:

Table 1 Risk classification for TBI (indications)

Considerable risk	Moderate risk	Minimal risk
Severely impaired consciousness worsening without improvement	Minor disturbances of consciousness	Mild or moderate posttraumatic headaches
Focal neurological signs	Progressive headaches accompanied by vomiting	*No loss of consciousness*
Penetrating head injury	Fracture of the skull base	
	Patients with multiple injuries	

2.1 TBI imaging Protocols

There is still no standardization for TBI CT protocols across institutions, different protocols can be found in the available literature, which varies in timing acquisition and the number of phases (Lacobellis et al. 2020). However, NCCT trauma remains the modality of choice as it quickly and accurately provides diagnoses in any emergency setting (Kim and Gean 2011). The NCCT trauma brain protocol will produce bony algorithms and soft tissue algorithms in one scan (Lampignano and Kendrick 2020). Below is an explanation stipulating general protocol procedure for NCCT.

2.1.1 General Protocol for NCCT

Patient positioning starts with the patients' head in the bore of the machine while the radiographer ensures that the patient is comfortable. Usually, the fundamentals of general radiography skull positioning apply to CT, depending on departmental protocols and the radiologist's request (Lampignano and Kendrick 2020). According to Schweitzer et al. (2019), the radiographer should immobilize the patient using sponges on either side of the patient's head and secure with Velcro straps. This will alleviate any possible rotation (Lampignano and Kendrick 2020). This procedure usually requires no breathing technique. On the Multi-Slice CT (MSCT), the radiographer needs to center on supra orbito-meatal line to ensure radiation reduction to the patient's eyes (Schweitzer et al. 2019). Furthermore, if a routine brain is requested, the radiographer must use the axial technique; however, to supply more information, coronal views may be requested.

Schweitzer et al. (2019) suggest that coronal view positioning can be achieved through two methods, with the patient either supine or prone. In the prone position, the patient must extend the chin and in the supine position, the patient must drop the head back as far as possible and be positioned in a special holder. The gantry may be angled to obtain a more coronal plane should there be challenges with positioning. Irrespective the final images should be the same in either position (Schweitzer et al. 2019).

Routinely a general NCCT covers the base to the vertex of the skull in 5–8 mm (Lampignano and Kendrick 2020). Whereas Schweitzer et al. (2019: 240) recommend specific algorithms that can be used to make a 3D reconstruction. In contrast, Kumamaru et al. (2016) suggest that 3D reconstruction protocol should only apply to difficult or restless patients.

There might be a few challenges with imaging the posterior fossa in CT. This is due to the significant varying beam attenuation ability between the opaque bone of the skull and the much less opaque parenchyma thus causing streak artifacts. The radiographer can avoid this intrinsic limitation by reducing the slice thickness CT of the posterior fossa and increasing the kVp settings (Schweitzer et al. 2019).

3 Stroke (nTBI)

Stroke is characterized by sudden onset of symptoms, depending on the area of the brain affected, and the most common clinical signs are sudden onset of facial weakness, unilateral hemiplegia, and abnormal speech (Thurnher 2012). Stroke is subject but not limited to various risk classifications which can be separated into modifiable and non-modifiable risk classifications (Zafar et al. 2016) as listed below:

Modifiable risk characteristics:

- Age
- Gender
- Ethnicity
- Genetics
- and Race

Non-modifiable risk characteristics:

- Hypertension
- Diabetes mellitus
- Hypercholesterolemia
- Atrial fibrillation
- Smoking
- Alcoholism

As a result, stroke is regarded as one of the leading causes of death and the leading cause of long-term disability worldwide (Myint et al. 2017) and its effect is well known worldwide and in South Africa (Daffue et al. 2016). The term stroke is usually used vaguely when referring to neurological symptoms that may represent cerebral infarction and cerebral hemorrhage. Furthermore, stroke is defined as a focal neurological deficit that persists for more than 24 h owing to the interruption of the blood supply to the brain, this definition shows a contrast between stroke and transient ischemic attack (TIA), which does not persist beyond 24 h but can be otherwise clinically identical (Mair and Wardlaw 2014). Three main stages are used to describe the CT manifestations of stroke: acute (less than 24 h), sub-acute (24 h to 5 days), and chronic (weeks) (Igbaseimokumo 2009). So, protocols for stroke must be set to give an immediate diagnosis to allow the necessary management soonest thus rapidly acquiring and interpreting NCCT images of a patient suspected of having an acute stroke is critical (Potter et al. 2019). Therefore, non-invasive cross-sectional imaging plays a crucial role in the assessment, planning, and follow-up of vascular disease (Murphy et al. 2019).

3.1 Stroke (nTBI) imaging Protocols

The aim of brain imaging in stroke patients is the detection of the relevant ischemic tissue pathology (Forster et al. 2012). The choice of protocols is determined by the indications the patient presents with. Stroke imaging usually includes NCCT, CT perfusion, and CT angiography (aortic arch to the vertex of the skull) (Macellari et al. 2014).

3.1.1 Non-contrast CT (NCCT) for Stroke

NCCT is usually listed as a primary imaging modality for acute stroke for several reasons such as availability, quick examination, therefore, allowing easier management of unstable patients (Mair and Wardlaw 2014). Reducing delays in diagnosis and treatment remains paramount to effective treatment of ischemic cerebrovascular (CVA) events (Jenson et al. 2019). Therefore, this protocol aims to rapidly diagnose and quantify strokes to enable proper urgent management. NCCT can show the early signs of a stroke, but most importantly will exclude intracerebral hemorrhage (ICH) and lesions that might mimic acute ischemic stroke (Birenbaum et al. 2011; Lee 2017). NCCT is also used in the evaluation of acute ICH as it produces good contrast between the high attenuating (“bright”) clot and the low attenuating (“dark”) cerebrospinal fluid (CSF) (Birenbaum et al. 2011). In addition to the clear distinction by NCCT, the protocol also provides some information on the presence of arterial thrombus usually seen as the hyperdense artery sign and on the extent of ischemia seen as a loss of gray-white matter differentiation, hypoattenuation of brain tissue, and evidence of swelling (Mair and Wardlaw 2014). The images in Fig. 1a show ischemic stroke which appears darker on the right and Fig. 1b shows a brighter hemorrhagic stroke on the left.

NCCT also provides information regarding the volume of blood, an extension to the cerebral parenchyma, the presence of hydrocephalus, and the potential location of the aneurysm (Caceres and Goldstein 2012). However, on occasion NCCT can result in incorrect diagnosis or delay in diagnosis of brain pathology (Minné et al. 2014). Figure 2 shows the middle cerebral artery (MCA) on the left MCA territory. This sign is usually identified as attenuation at the center of the main stem (M1) portion of the MCA (Chieng et al. 2020). While skull base streak artifact can mimic the hyper-attenuating MCA sign due to the beam hardening from the bones (Chieng et al. 2020), coronal and sagittal reformations can improve visualization and help one distinguish artifact infarct and hemorrhage (Potter et al. 2019). NCCT is considered to have a low sensitivity for the depiction of hyper-acute and early acute hypo-attenuating ischemic changes hence an acute territorial infarct is mostly visible once it is greater than one-third of the MCA territory (Potter et al. 2019). Contrast media may be administered when further information is necessary.

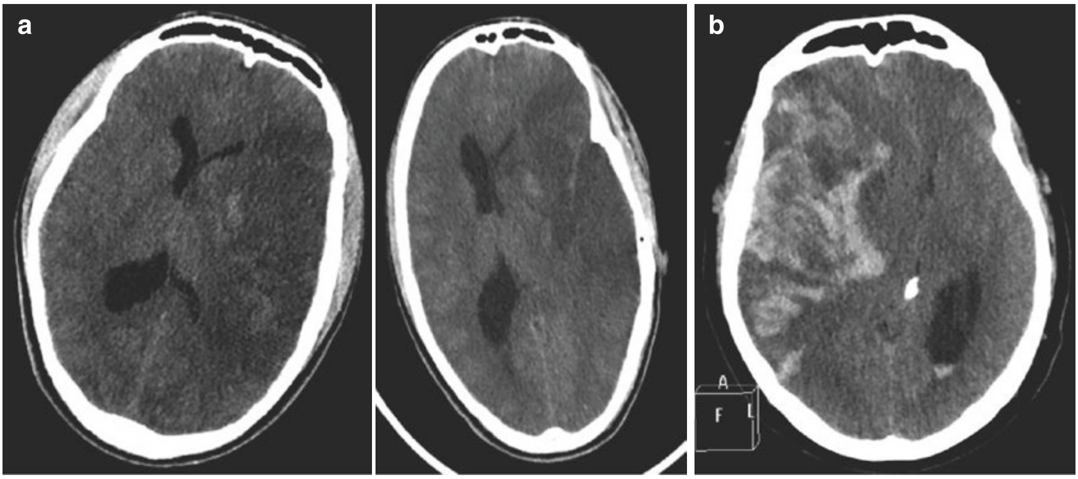

Fig. 1 Ischemic (**a**) and hemorrhagic stroke (**b**) (Milpark Radiology 2020)

Fig. 2 MCA sign (Milpark radiology 2020)

3.1.2 Contrast Media (CM) Considerations

Guidelines published in the past decade recommend that patients should be screened for possible renal failure before CM administration intravenously however in cases of CTA for stroke (nTBI) and TBI protocols are initiated without information regarding CM allergy and renal function history due to the acute presentation in the emergency setting (Khosravani et al. 2013). Hence, the value of CT has seen an increasing appreciation with regard to hematoma growth and CM enhancement of the spot sign (Aguilar and Brott 2011). Almost all CT procedures of the brain require CM injection which may be introduced either through low-pressure hand injection or via a high-pressure injector (Lampignano and Kendrick 2020).

Brain tissue has a natural selective diffusion barrier that allows only certain substances through and is termed the blood–brain barrier (Abbott et al. 2010). In cases of intra-parenchymal and subarachnoid hemorrhage, the blood–brain barrier will show CM outside of normal vasculature (Lampignano and Kendrick 2020). Tube voltage X-ray energy is an important factor affecting CM enhancement because vascular opacification is directly proportional to iodine delivery to the region of interest (ROI) (Saade et al. 2016). This proportionality increases with decreasing CT tube voltage, leading to increased vascular opacification, as X-ray photon energy gets closer to the K-edge of iodine at lower voltages (Saade et al. 2016). Therefore, it may be concluded that low voltage not only improves vascular opacification, but it also reduces the volume and concentration of CM needed and the radiation dose administered to the body (Cho et al. 2012).

The injection rate is also another factor that will help determine the opacification necessary for a specific study. With regard to MSCT, an injection rate of 4–5 ml/s is usually sufficient in providing excellent arterial opacification for most vascular studies; venous imaging does not require as high injection rates (Murphy et al. 2019). Usually, long scan durations necessitate long injection times and short scan durations can be performed with short injection times (Saade et al. 2016). Altering how CM is distributed to show the vascular tree completely is important when using helical scanners as they cover a larger scan range quicker (Saade et al. 2016). Thus, the shortest possible scan duration is an important variable that needs to be considered when designing protocols related to CTA (Cho et al. 2012).

3.1.3 CT Perfusion (CTP)

CTP is commonly used in acute stroke (nTBI) patients but can be used in TBI patients where CM can be administered using different variables to ascertain cerebral perfusion (Lui et al. 2010). It may be imperative to note that adding CTP will add approximately 10–15 min to the scanning time, which includes processing (Lui et al. 2010). CTP is mostly useful for differentiating the core of the infarct from the penumbra (Lukies and Gaillard 2020). Therefore a higher index indicates a greater relative size of penumbra and therefore better prognosis as seen in Fig. 3 where the penumbra and infarct size seen on MCA territory indicate a potential recuperation ratio (PRR) of 75.38%. This procedure is usually performed by sequentially imaging a defined section of tissue after a single high-flow bolus of CM is administered (Potter et al. 2019). CTP is therefore used to produce useful perfusion maps while adhering to ALARA, radiologists need to understand patterns and issues with interpretation, as the role of CTP grows in the diagnosis and treatment of acute stroke (Lui et al. 2010). The pivotal factor to CTP is the interpretation of several perfusion parameters, among which cerebral blood flow post a single bolus of CM injected during the use of MSCT scanner (Munich et al. 2016).

Through CTP the following variables can be estimated: cerebral blood flow (CBF) (Fig. 3a), cerebral blood volume (CBV) (Fig. 3b), time to peak (TTP) (Fig. 3c), and mean transit time (MTT) (Fig. 3d) (Munich et al. 2016; Lin et al. 2013). These variables may be used to estimate areas of irreversible brain damage and potential salvageable areas of hypoperfusion (Borst et al. 2015). Munich et al. (2016) state that CBF is measured in mL of blood per 100 g of parenchyma per minute (normal: 50 ml/100 g/min), while CBV is measured in mL of blood per 100 g of parenchyma (normal: 5 ml/100 g); MTT is a measurement of the meantime for blood to travel through a given volume of the brain, to show the duration of the CM bolus to travel from the arterial to the venous circulation (Konstas et al. 2009). TTP is therefore considered the delay between the first entry of CM intracranially and the period taken by the CM to reach its maximum concentration within the area of interest in the parenchyma (Lin et al. 2013). In most tertiary

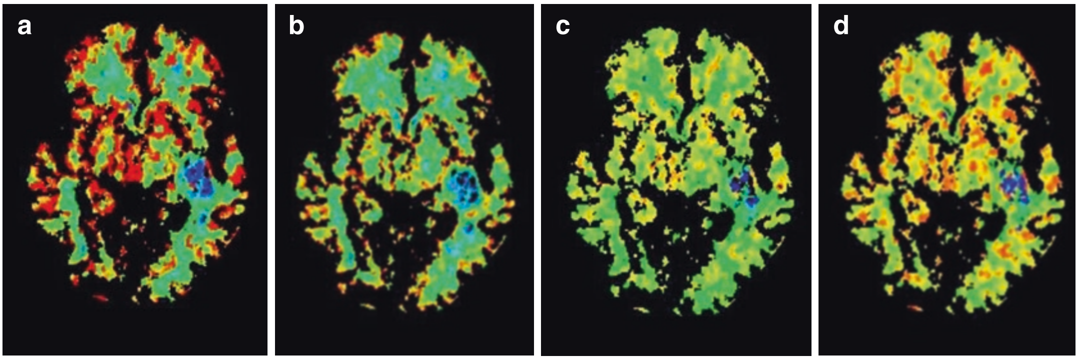

Fig. 3 CBF (**a**), CBV (**b**), TTP (**c**) and MTT (**d**) (Milpark Radiology 2020)

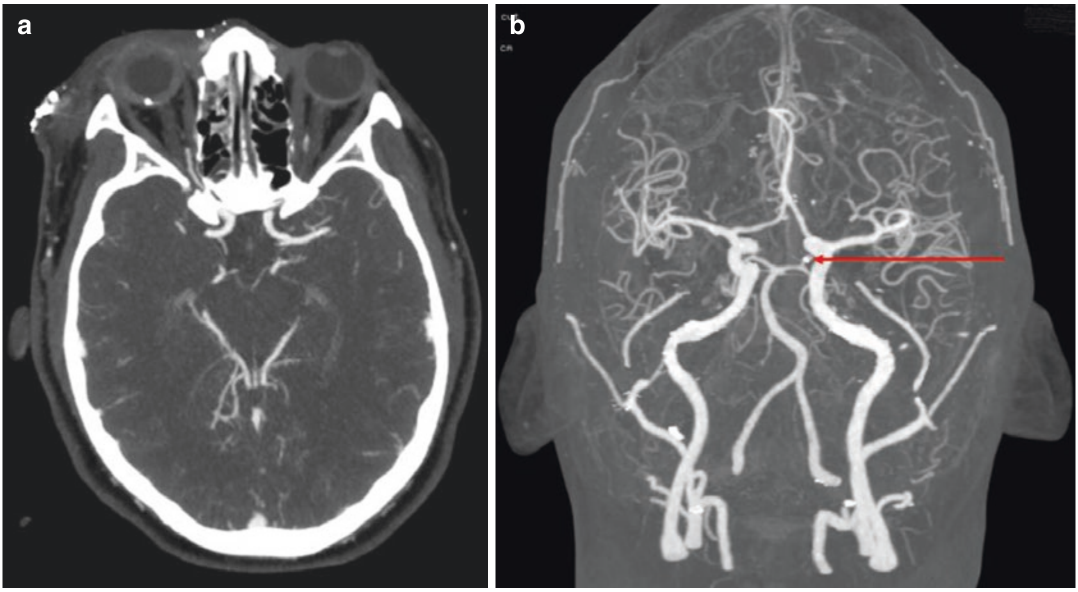

Fig. 4 CTA axial image (**a**) (Milpark Radiology 2020) and CTA of the COW showing spot sign (**b**) (Mashao and Dzichauya 2020)

stroke centers, CTP with cerebral blood flow, cerebral blood volume, and mean transit time is usually done concurrently with CTA to help differentiate between hemorrhagic infarct and intracranial hemorrhage (Choi et al. 2012).

3.1.4 CT Angiography (CTA)

The CTA protocol is fundamental to advanced treatment choice in acute ischemic stroke as a screening tool to exclude the possibility of hemorrhage and occlusion of vessels (Choi et al. 2012; Hemphill et al. 2015). Although only an NCCT is necessary to rule out hemorrhage to administer CM to eligible patients, many stroke centers have long used CTA (Fig. 4a) to detect carotid stenosis, intracranial atherosclerosis, and large vessel occlusions at the time of presentation (Douglas et al. 2015). CTA is non-invasive; available worldwide (Douglas et al. 2015), preferred as it provides high spatial resolution and saves time compared to the conventional method in assessing TBIs (Romans 2011; Lolli et al. 2016). Usually, the procedure requires the use of a high-pressure injector to allow uniform high injection rate CM bolus delivery, and use of a saline flush should be routine to help push the tail of the CM bolus into the central blood volume because the bolus tail would remain unused in the peripheral veins if saline is not administered (Murphy et al. 2019).

CM leaking from the hematoma may help identify the "spot sign" (Fig. 4b) which can save those patients that are at risk of poor neurological outcomes due to the hematoma expanding in case of an ischemic stroke (Mirza and Gokhale 2017; Macellari et al. 2014; Vilela and Wiesmann 2020; Al-Mufti et al. 2018). The spot sign is recognized as a factor that helps with identifying the hemorrhagic areas in the brain during CTA (Zhang et al. 2018). It is important to note that CTA is not performed routinely in the acute phase in most clinical settings due to the cost and time to execute as compared to NCCT (Zhang et al. 2018).

4 General Considerations of Findings on CT Scan TBI and nTBI

Currently, there are numerous studies about nTBI evaluation and acquiring outcome information concerning the seriousness of the TBI (Mutch et al.2016). According to Igbaseimokumo (2009), the basics of CT brain scans include consideration of three basic densities. The author states that the density of TBI lesions seen on CT can be hyperdense (white), hypodense (darker tone), and isodense (the combination of hyper and hypo densities). In particular, the most common hyperdense irregularity in brain CT scan is the blood which changes over time. The pineal gland and coracoid processes are the only exceptions to "everything white is blood" (Igbaseimokumo 2009).

The appearance of an ICH on CT changes as time progresses (Romans 2011). During the first imaging evaluation in a patient with a stroke, it is paramount to establish if there is an ICH or a large, well-established, hypo-attenuating territorial infarct (Potter et al. 2019). This is due to the red blood cells within the hemorrhage which deteriorate within several hours after leaving the vasculature (Romans 2011). These changes are complex and depend on many factors, such as whether the patient is anemic and to what degree the blood has mixed with CSF (Macellari et al. 2014). Initial rapid NCCT evaluation within 4.5 h from the onset in patients without other contraindications should focus on identification of a large territorial infarct and exclusion of ICH (Potter et al. 2019).

CT imaging can assist with approximating the age of hematomas, by assessing the density of the lesions measured in Hounsfield units (HU) which are related to the estimate of X-ray attenuation corrected for the coefficient of water (Macellari et al. 2014). According to Baldon et al. (2020), biological processes of the hematoma on acute TBI are similar to that of primary nTBI (Stroke) since the development of the hematoma results in secondary injury to the surrounding brain parenchyma, thus promoting mass effect which increases intracranial pressure with further brain injury. The density of the hematoma on CT in the case of TBI may be associated with the age of the hematoma over time and the number of foci of the hemorrhage as well as to hematocrit (Barras et al. 2009). The density of the hematoma generally reduces with time which may sometimes pose issues for detection of sub-acute and chronic hemorrhages that may show isodense to the surrounding brain tissue (Mutch et al. 2016). The TBI hematoma is usually the result of ruptured vessels within the brain and the leaking blood then causes a circumscribed area of edema which later determines patient prognosis as they both expand following the first insult (Al-Mufti et al. 2018: 119). Figure 5 demonstrates a case of worsening cerebral edema concerning the left-sided infarct with mass effect and midline shift.

The evolution of hematoma on TBI and nTBI CT images is therefore dependent on the location of hemorrhage and usually clears faster on CSF spaces (Vilela and Wiesmann 2020). Within the immediate first hours of the TBI, the hemorrhage will have similar attenuation as that of the cortex and is hard to differentiate (Mirza and Gokhale 2017; Vilela and Wiesmann 2020), notably known as the hyper-acute phase (Mirza and Gokhale 2017). Therefore, the TBI hemorrhage both hyperdensity (blood) and hypodensity (edema) components of hemorrhage change significantly within the first 24 h (Wilkes et al. 2018) being brightest the first day of the injury and slowly fading with time. For about 3 days, the

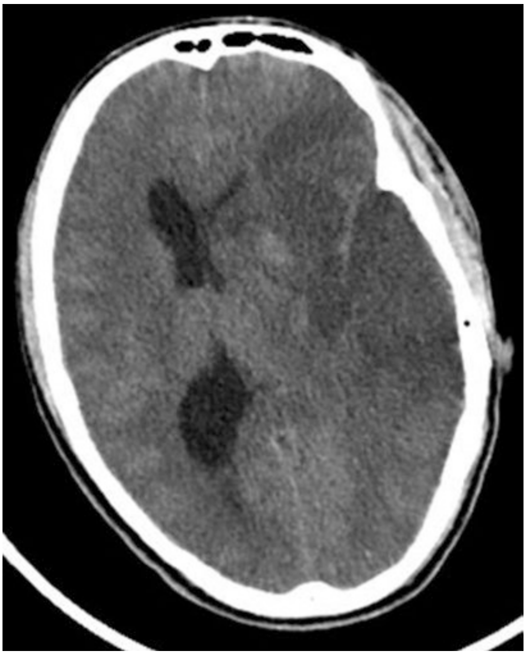

Fig. 5 Cerebral edema (Mashao and Dzichauya 2020)

hematoma is hyperdense to normal brain tissue, after which it will gradually decrease in density (Wilkes et al. 2018). Igbaseimokumo (2009) agrees by stating that the hematoma appears brightest on thin tissue for 3 days, after which it will gradually decrease in density. The edges around the hematoma may appear hypodense within the first and progress for up to 2 weeks post the TBI hemorrhage onset (Majidi et al. 2016). Within the 2 weeks, a hyperdense center surrounded by concentric areas of hyperdense and hypodense tissue can be seen on CT (Mirza and Gokhale 2017). About one and a half weeks (10–14 days), the hematoma density drops and is likely to show an isodense center surrounded by areas of hypodense tissue (Rao et al. 2016). By 6 months, the ICH will be hypodense to the brain.

The skull is not always symmetric owing to factors during CT positioning therefore radiologists measure the midline shift by drawing the Ideal Midline (IML) joining the most anterior and posterior visible points on the fall and then measuring the farthest point on the septum pellucidum as perpendicular from the IML (Brant and Helms 2012). Therefore, when considering brain CT findings, any shift of the midline structure is regarded as a lesion on the side from which the midline is displaced (Liao et al. 2018). Additionally, the scan is considered abnormal if the two sides of the brain show asymmetry, if the image is uniform on each slice, then the scan may be considered normal (Igbaseimokumo 2009).

Igbaseimokumo (2009) considers CSF as the compass of the brain, stating that it is important to be able to find the normal flow of CSF in the brain. Leakage of CSF is found in 2% of all TBI patients and 12–30% of cases of basilar skull fractures (Parizel and Philips 2020). Typically, brain swelling is when the gyri appear larger and the sulci smaller (Igbaseimokumo 2009).

During CT TBI and nTBI consideration of findings, narrow window widths are used to show the brain, due to the slight variation in attenuation between the gray matter and the white matter (Romans 2011). It is further explained that the slightly higher attenuation of the gray matter of the brain compared with the white matter may be a result of both lower gray matter water content and a higher blood volume. Usually, the density of tissue on CT is estimated by HUs whereby lower density tissue will show lower HU and the other way around (Kim et al. 2019). The HU for water is equal to 0, blood is between 30 and 45, the gray substance is between 37 and 45, the white substance is between 20 and 30, while the bone is between 700 and 3000 (Macellari et al. 2014; Bhargava 2019). Note that HU scale zero refers to pure water; the value of cerebrospinal fluid (CSF) is slightly above that of water (Romans 2011). Variability in HU values is distinguished by the protocol parameters for a particular examination (Kim et al. 2019).

Most primary findings emanate from TBI and include scalp injuries, skull fractures, extra-axial, and intra-axial hemorrhages, whereas secondary findings stem from complications of primary findings which are inclusive of ischemic and damage due to lack of oxygen, cerebral edema, and brain herniation (Lolli et al. 2016). So, to allow proper planning for management on either finding a trauma assessment system will provide information on the seriousness of the TBI (Mahadewa et al. 2018). In rare cases, neurological examinations may be unreliable following sedation in patients with severe TBI, therefore CT prediction outcomes for TBI which allows classification according to the damage demonstrated on neuroimaging is an important primary role in the early management of TBI and in predicting secondary effects thereof (Lolli et al. 2016). Below is a brief description of common classification systems used in CT TBI cases:

- The Marshall classification system of traumatic brain injury (MCTC) score was published in 1992 which shares correspondence between TBI on CT and intracranial pressure. This is a CT-scan derived metric using only a few features and has been shown to predict outcomes in patients with TBI (Mahadewa et al. 2018).
- The Rotterdam score system (RSS) is a more recent tool that is useful in prognosis of mortality of patients with severe TBI by ensuring prediction of outcome based on abnormalities detected, for example, basal cisterns' condi-

tion, midline shift, traumatic subarachnoid or intraventricular hemorrhage, and epidural hematoma (Charry et al. 2017).

- Helsinki CT score tool is another classification system, which considers bleeding type and size, intraventricular hemorrhage, and suprasellar cisterns (Lolli et al. 2016). The Helsinki CT score provides an accurate prognosis in patients with mildly complicated, moderate, or severe TBI due to its ability to predict long-term outcomes (Yao et al. 2017).

5 Common Primary Findings for TBI and nTBI Explained

NCCT shows extra-axial hemorrhage, intra-axial hemorrhage, and skull fractures (Haaga and Boll 2017; Kim and Gean 2011). See Table 2 below:

With regard to hemorrhage, the type of hemorrhage depends on location and whether it is an arterial hemorrhage or venous hemorrhage. The benefits of CT for TBI assessments are the responsiveness to acute extra-axial and intra-axial hemorrhages, mass effect, ventricular size, and skull fractures (Lolli et al. 2016). Epidural and subdural hematomas are generally associated with TBI however they may also be the result of nTBI (Vilela and Wiesmann 2020).

5.1 Epidural Hematoma

Epidural hematoma (Fig. 6) is an acute arterial bleed, between the skull and dura mater. Laceration of the medial meningeal artery results in this complication (Parizel and Philips 2020). Epidural hematoma is usually associated with significant mass effect midline shift and acute neurological symptoms (Heit et al. 2017). On CT, it can be identified in the periphery as a lens-shaped (biconvex), high-density lesion (Khairat and Waseem 2020).

5.2 Subdural Hematoma

A subdural hematoma is a venous hemorrhage between dura mater and arachnoid mater, resulting from rupture of veins in the dura meninges (Heit et al. 2017). Symptoms develop over a course of time. The hematoma is usually found adjacent to the inner table of the skull as a crescent-shaped high density (Heit et al. 2017). The density decreases overtime on CT. Figure 7 illustrates a traumatic acute right-sided subdural

Fig. 6 Epidural hematoma (Mashao and Dzichauya 2020)

Table 2 Common Findings in CT scan for TBI and nTBI

Extra-axial hemorrhage	Intra-axial hemorrhage	Skull fractures
Epidural	Cortical contusion	Linear fractures
Subdural	Intra-parenchymal hematoma	Depressed fractures
Subarachnoid/intraventricular	Shear injury	Basilar fractures

hematoma with associated midline shift and subglacial hematoma.

Fig. 7 Subdural Hematoma (Mashao and Dzichauya 2020)

5.3 Subarachnoid/Intraventricular hematoma

According to Parizel and Philips (2020), injury to surface veins, cerebral parenchyma, or cortical arteries may result in a subarachnoid/intraventricular hematoma. Additional to that the bleeding is produced into the ventricular system sometimes resulting in hydrocephalus and it can be identified on CT as a hyperdensity in the subarachnoid space. Figure 8b demonstrates a finding of blood in the area of the circle of Willis consistent with acute subarachnoid hemorrhage with no evidence of hydrocephalus (Fig. 8a).

5.4 Intra-Axial Hemorrhage

According to Ullah et al. (2015), "Intra-axial hemorrhage is bleeding within the brain itself." This category includes intraparenchymal hemorrhage, or bleeding within the brain tissue, and intraventricular hemorrhage, bleeding within the brain's ventricles.

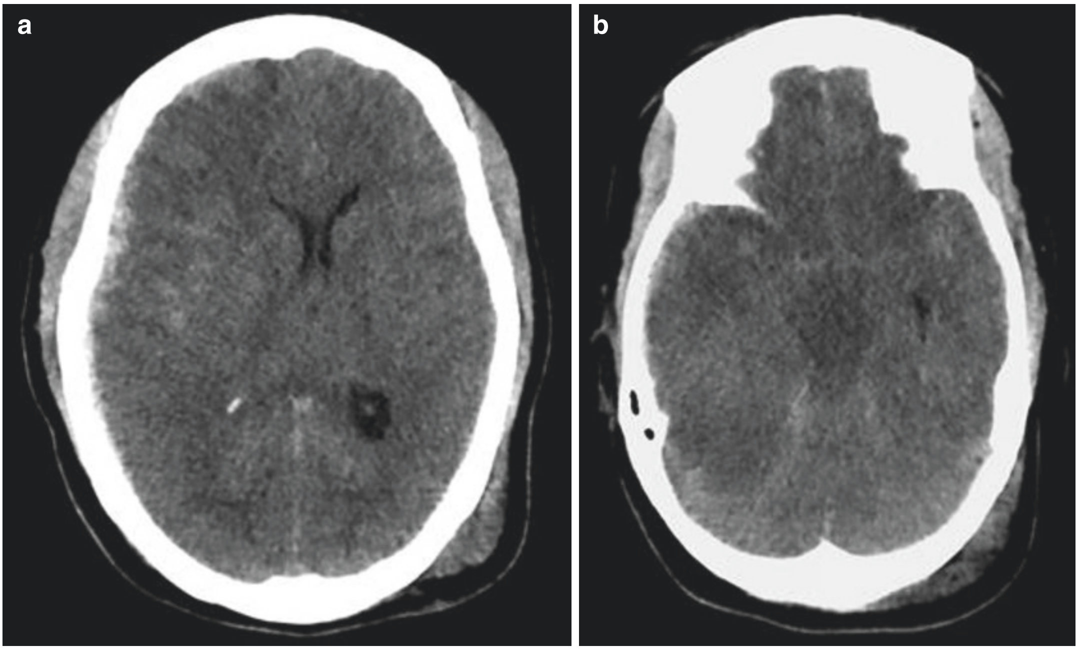

Fig. 8 Subarachnoid/intraventricular (**a** & **b**) (Milpark Radiology 2020)

5.5 Intraparenchymal Hematoma (IPH)

Intraparenchymal hematoma (IPH) refers to hemorrhaging in the brain parenchyma (Mirza and Gokhale 2017). Figure 9 shows NCCT of the brain showing right frontal lobe IPH surrounded by edema. Stroke (nTBI) IPH in older patients is the result of hypertensive individuals, with cerebral amyloid angiopathy also noteworthy in normotensive individuals (Cox et al. 2017). Rapid brain imaging is recommended to differentiate ischemic stroke and IPH, whereas CTA may be undertaken to identify those patients that are at risk of hematoma expansion (Morgenstern et al. 2010; Khosravani et al. 2013). Acute IPH is usually detected by NCCT an intra-axial hyperdense region of hemorrhage that is classically centered within the basal ganglia, cerebellum, or occipital lobes (Vilela and Wiesmann 2020; Patel et al. 2019).

IPH volume can be calculated by using the ABC/2 method (Huttner et al. 2006). According to these authors, the ABC/2 method adheres to the steps depicted below:

Fig. 9 Intraparenchymal hematoma (IPH) (Milpark radiology 2020)

- A is the largest hemorrhage diameter on the selected slice in centimeters (cm) by CT (Fig. 10a).
- B is the largest diameter perpendicular (90°) to A on the same slice (Fig. 10a).
- C is the approximate number of CT slices in which the hemorrhage is seen multiplied by the slice thicknesses often 0.5 cm slices, Fig. 9b shows 2.82 cm (Fig. 10b).

A, B, and C are then multiplied, and the product is divided by 2 (Kothari et al. 1996).

5.6 Cortical Contusions

Cortical contusions are bruises of the brain parenchyma due to impact at the coup and contra coup sites, most commonly in the inferior frontal lobes and anterior-inferior temporal lobes (Schweitzer et al. 2019). These TBIs are characterized by hyperdense lesions within the brain parenchyma itself, and they are caused by a micro-vascular arterial or venous injury. A follow-up CT is necessary to monitor any growth of the hematoma, thus the radiographers and radiologists need to be aware of this to avoid premature discharging of patients due to inadequate monitoring (Heit et al. 2017). The CT presentation of cortical contusions is heterogeneous, hyperdense cortical lesions surrounded by an irregular margins hypodense (edematous) component (Parizel and Philips 2020). Figure 11 demonstrates cortical contusion on the left inferior frontal lobe.

5.7 Skull Fractures

Skull fractures are caused by high energy impact exceeding the mechanical integrity of the calvarium and are usually associated with severe TBIs (Gitto et al. 2015: 44). Skull fractures may be missed on initial CT scan as thicker slices are set for the routine NCCT; however, follow-up CT could detect the fractures as thinner slices are used and reconstructed sagittal CT will assist in demonstrating the fracture effectively (Hosaka et al. 2015: 3).

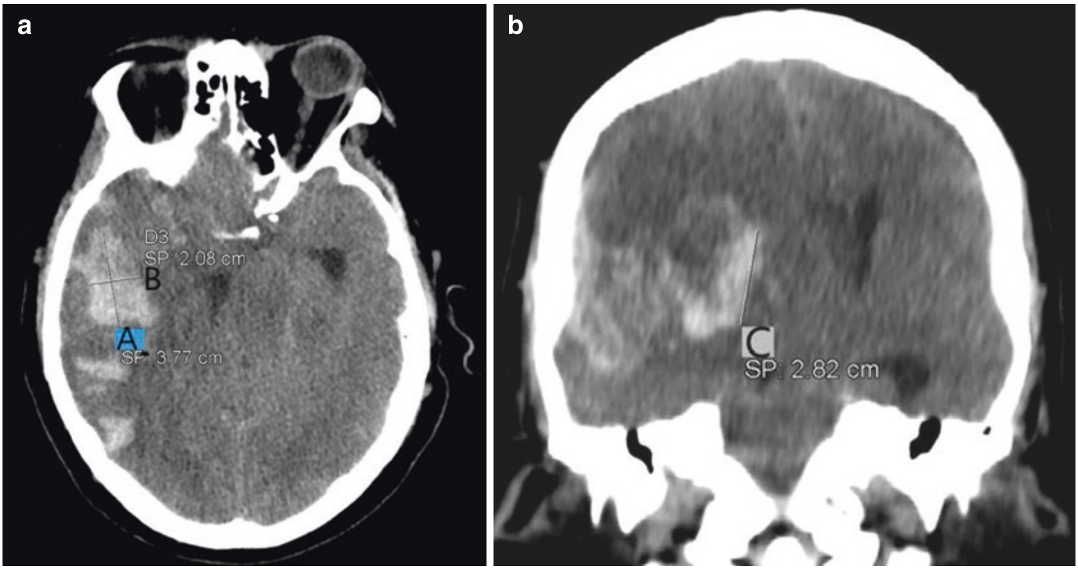

Fig. 10 (**a** and **b**): ABC/2 method (Milpark Radiology 2020)

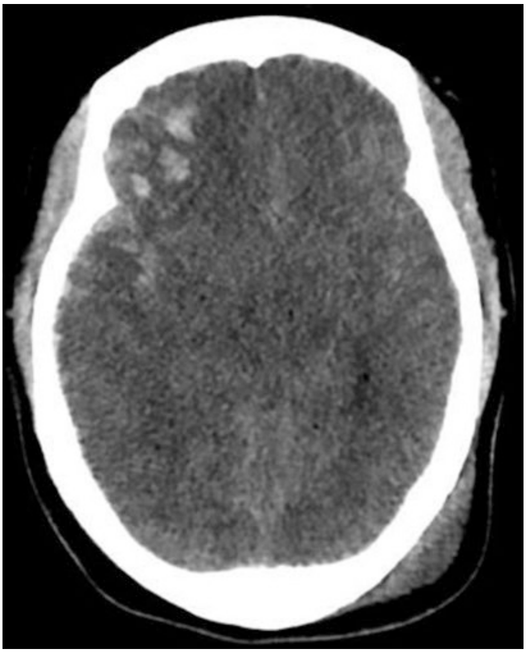

Fig. 11 Cortical contusion (Milpark Radiology 2020)

There are three main types of skull fractures, namely linear fractures, depressed fractures, and basilar fractures (Haaga and Boll 2017). The NCCT results may not demonstrate fractures that are linear and non-displaced, therefore MDCT with thinner slices may be recommended if there is a high suspicion for basilar skull fractures (Haaga and Boll 2017). On the other hand, the smaller vasculature presented on MDCT may be incorrectly considered as fractures (Simon and Newton 2020) and linear fractures that come in the plane of a CT slice may not be shown unless they are depressed or separated (Chawla et al. 2015). CTA is usually recommended to confirm vascular injury in such critical settings (Simon and Newton 2020).

Basilar fractures have various presentations depending on the severity of the head injury (Mokolane et al. 2019). A basilar fracture is defined as any fracture involving the floor of the anterior, middle, or posterior cranial fossa that results from substantial blunt force trauma (Simon and Newton 2020). The presence of clinical signs such as raccoon eye, rhinorrhea, rhinorrhagia, anosmia, visual impairment, otorrhea, otorrhagia, hearing loss, neurovascular injuries, battle sign, phonation problems, vocal cord paralysis, and/or aspiration are regarded as significant predictors of basilar fractures (Mokolane et al. 2019). TBIs with basilar skull fractures may advance to have vascular air embolism if the air was not identified on initial examination (Kai et al. 2020).

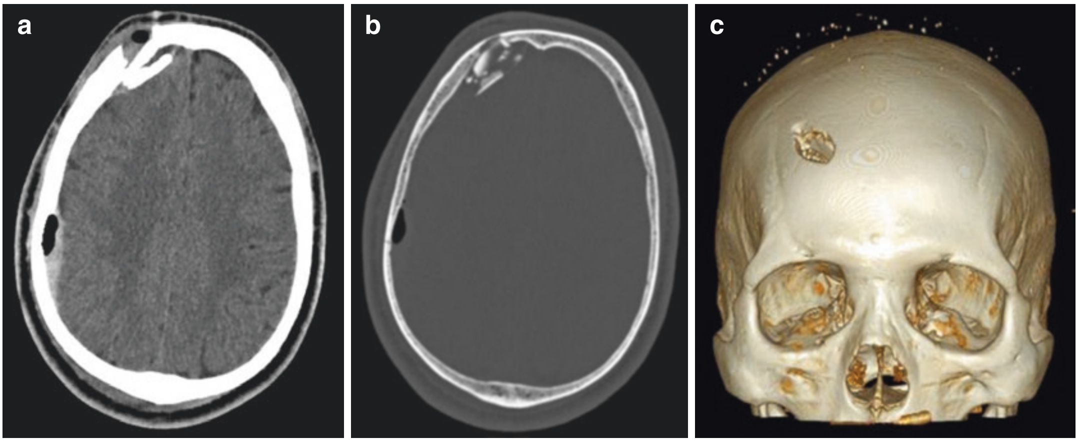

Fig. 12 Soft tissue window (**a**), bone window (**b**), and 3D reconstruction of depressed skull fractures (**c**) (Milpark Radiology 2020)

Depressed skull fracture arises when pieces of the fractured skull press inward causing trauma to the brain (Gitto et al. 2015). The most common dural sinus injury usually results from depressed skull fracture over superior sagittal sinus with notable fatalities (Ahmad et al. 2018). Figure 12a shows a depressed skull fracture viewed in a soft tissue window algorithm. NCCT with 3D reconstructions (Fig. 12b) and bone window algorithms (Fig. 12b) can help to establish a clear TBI diagnosis in case of suspected depressed fracture (Ibrahimaa and Motah 2015).

6 Common Secondary Findings in CT TBI and nTBI

Secondary findings are usually the result of complications; hence they are more critical than primary effects (Bae et al. 2014). These may include the development of new hemorrhage, worsening vasogenic edema, or cytotoxic edema, which all promote the increase of the intracranial pressure that will subsequently introduce herniation, ischemia, and infarction (Haaga and Boll 2017).

6.1 Hemorrhagic Stroke

There are two main types of hemorrhagic strokes, namely ICH (Fig. 1b) and subarachnoid hemorrhage (SH) (Fig. 8) which accounts for about 5% of all strokes (Macellari et al. 2014). ICH is described as spontaneous extravasation of blood into the brain parenchyma associated with high mortality and disability (Senn et al. 2014). The location of the ICH can be classified as deep, lobar, and infra-tentoria. Moreover, Domingues et al. (2015) indicate that the anatomical location aid in identifying the underlying cause of bleeding.

According to Macellari et al. (2014: 903), the NCCT brain is commonly used for diagnosis in case of acute stroke because of its convenience and its high sensitivity for detecting ICH, which is a contraindication to thrombolytic therapy. Moreover, NCCT allows quantifying hematoma volume and monitoring of hemorrhage evolution in ICH accurately (Macellari et al. 2014: 903).

Domingues et al. (2015) state that NCCT also permits the identification of the anatomic distribution of the hematoma, extension to the ventricular system, and estimation of hematoma volume. Furthermore, ICH appears as a hyperdense lesion within minutes after the onset of symptoms, however NCCT has decreased sensitivity 1 week after ICH onset because the lesion becomes isodense concerning the brain parenchyma (Domingues et al. 2015).

6.2 Transient Ischemic Attack (TIA)

Transient ischemic attack (TIA) and minor ischemic stroke are associated with brain dysfunction in a circumscribed area caused by a regional reduction in blood flow resulting in either transient or minor observable clinical symptoms (Coutts 2017). TIA is a medical emergency and forewarns of an imminent stroke (Siket and Edlow 2013). A TIA is a clinical syndrome characterized by the sudden onset of a focal neurologic deficit presumed to be on a vascular basis (Simmons et al. 2012). The ABCD^2 (age, blood pressure, clinical presentation, diabetes mellitus, duration of symptoms) score estimates the risk of stroke following a suspected TIA (Salunke et al. 2020). The ABCD^2 method should be determined during the initial evaluation and risk assessment of repeat ischemia and stroke, i.e., the higher the score the greater the probable severity of the stroke (Simmons et al. 2012). Therefore, imaging can support the diagnosis, but TIA is primarily a clinical diagnosis. Three challenges identified in the management of patients with TIA include (Yu and Coutts 2018):

- Rapid accurate diagnosis.
- Establishing mechanism of stroke and the risk of early reoccurrence.
- Precipitate investigations and treatments.

Therefore, the use of neuroimaging in TIA is crucial for both diagnosis and accurate risk-stratification (Sorensen and Ay 2011). Patients with minor ischemic stroke and TIA who are at the highest risk of recurrent events and disability can be identified using non-invasive CTA (Coutts 2017). Interestingly several studies (Forster et al. 2012; Yu and Coutts 2018; Moreau et al. 2013) suggest that CT imaging is unable to positively detect suspected ischemic lesions due to its low sensitivity in detecting very small cortical and subcortical infarctions (Forster et al. 2012). Infarcts discovered in TIA are very small, lack edema and mass effect and show no or very subtle contrast enhancement (Sorensen and Ay 2011).

6.3 Traumatic Brain Herniation

Brain herniation requires immediate diagnosis as it is potentially life-threatening and may result in various issues secondary to compression of vessels, nerves, and the ventricular system (Gilardi et al. 2019). Kim and Gean (2011: 47–48) have identified several variations when brain herniation is considered, these variants are described briefly:

- Subfalcine herniation is commonly referred to as midline shift and occurs when the cingulate gyrus herniates under the falx cerebri.
- “Uncal herniation results when the medial temporal lobe herniates through the tentorial incisura and compresses the ipsilateral suprasellar cistern” (Kim and Gean 2011: 47)
- Descending transtentorial herniation occurs with downward herniation of both temporal lobes through the tentorial incisura, compressing the basilar cisterns.
- Upward transtentorial herniation occurs in the opposite direction, with the cerebellum extending through the tentorial incisura and effacing the quadrigeminal cistern.
- Tonsillar herniation results when the cerebellar tonsils herniate into the foramen magnum.

CT characteristics of brain herniation usually include widening and displacement of structures in the brain depending on the variant manifesting with the given case. Probst et al. (2009) state that brain herniation on CT findings can be classified under three categories, namely the frank herniation; significant shift, without frank herniation; or minimal or no shift. Refer to Fig. 13 to appreciate the manifestation of a significant midline shift to the left with compression of lateral ventricles.

6.4 Ischemic Stroke

Rapid neuroimaging to differentiate an ischemic stroke from ICH (Fig. 1a, b) is vital to patient management (Osborn et al. 2018). According to the American Heart Association/ American Stroke Association (AHA/ASA) guidelines for evaluation, screening and initial treatment to determine ischemic stroke should be performed expeditiously (Jauch et al. 2013). Focal sulcal effacement is an important early secondary sign of acute ischemia and can help identify subtle acute infarcts (Potter et al. 2019).

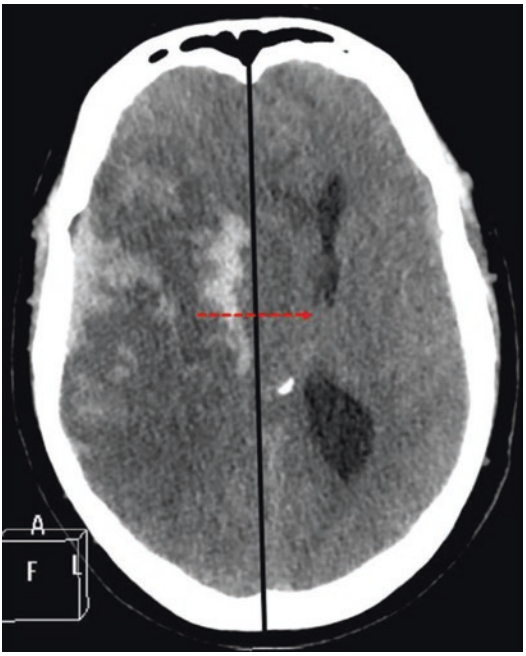

Fig. 13 Brain herniation (Milpark radiology 2020)

6.5 Infarction

The sensitivity and specificity for acute infarction (Fig. 14) on NCCT likely depend on the duration, infarct size, and degree of ischemia (Potter et al. 2019). The imaging findings of acute infarct can be difficult to notice in the following locations: the extreme vertex owing to volume averaging; the inferior temporal lobes, where the gray-white matter junction is oriented axially; the occipital lobes owing to frequent artifact caused by the irregular contours of the skull; and the deep gray matter, particularly the caudate heads. The insula, caudate heads, and basal ganglia show early findings of proximal middle cerebral artery (MCA) thrombosis at NCCT and should be carefully evaluated (Potter et al. 2019).

7 Emerging Protocols: (MSCT)

In principle, MSCT use has seen a legitimate rise in recent years due to its fast acquisition, wide availability, cost-effectiveness, and reliability in the detection of acute hemorrhage (Rosa-Junior et al. 2013). Secondly, MSCT is helpful as it reduces the number of deaths in emergency room patients while increasing the hospital's revenue (Imai et al. 2018). Thirdly, the use of MSCT has allowed the acquisition of thinner slices in a brief time due to the multi-row detector fitted within the unit. (Imai et al. 2018). Lastly, MSCT allows studies of the head to be routinely acquired with thinner slices than in the past with −1.25 mm thickness being typical. This is recommended for parenchymal assessment to ensure accuracy of slice thickness ranging from 0.5 to 3 mm and preferably with an arrangement of 0.5–1.5 mm (Lacobellis et al. 2020).

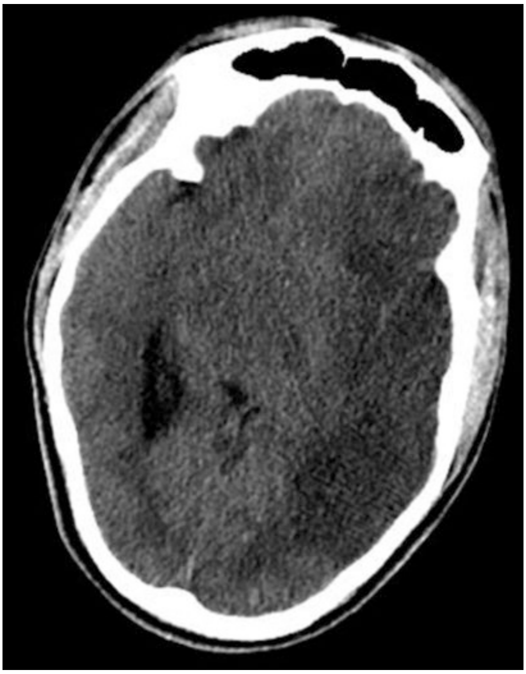

Fig. 14 Infarct on left MCA territory (Milpark Radiology 2020)

Romans (2011) supports the concept of thinner slices and states that thin slices help to reduce beam-hardening artifacts since they can be merged into thicker slices for viewing. To minimize motion artifacts, helical CT is often used for 3D reformations. In general, routine head studies are done using an axial mode, and CTA studies of the head and neck are done using a helical mode (Romans 2011). Cross-sectional slices of the brain are viewed in multiple window settings.

Windowing algorithms are important because some findings are not obvious (Koegel et al. 2018). For instance, other unique processing algorithms can demonstrate specific anatomy (Lampignano and Kendrick 2020) such as a magnified version of a small bony structure**.**

CT remains the primary imaging modality for emergent indications such as trauma and acute changes in neurologic status. Patient characteristics, contrast parameters, and CT scanning parameters are considered to affect image quality. Wherein, CT-related factors include scan duration, direction, contrast bolus arrival time, scan delay concerning contrast injection, and CT tube voltage (Saade et al. 2016). Therefore, in cases of fracture detection, using highly specialized 3D reconstruction algorithms which are designed especially for fracture detection will help remove misleading structures, such as vascular channels that could be mistaken for fractures (Ringl et al. 2010) and will allow for high-quality 3D reconstructions (Le and Gean 2006).

8 Standardizing CT Protocols

Despite the lack of standardized protocols, the aim of neuroimaging in the case of TBI and nTBI is always to supply information quickly to ensure quick decision-making without delay, thus avoiding secondary complications (Lin and Liebeskind 2016). Therefore, having standard protocols will ensure that all TBI and nTBI patients take priority over all other booked requests. In both cases of TBI and nTBI, it is imperative to adhere to standardized protocols, for instance, within some institution's patients presenting with acute ischemic stroke are considered candidates of both CPT and CTA (Munich et al. 201). Furthermore, Mair and Wardlaw (2014) postulate that to perceive the full prospects of CPT; a standardized CTP must be worked out. Consequently, without the CTP standardization, there are no set value estimates whereby poses a challenge in detecting penumbra and the infarct core. Similarly, this can be correlated in CT protocols for TBI and nTBI in general, that any attempt to standardize CT protocols may require careful thought (Mair and Wardlaw 2014).

Kumamaru et al. (2016) state that it is important to develop protocols that can be followed by any radiographer regardless of their skill level because radiographers are expected to carry out these protocols precisely while taking care of the patient (Trattner et al. 2014). Therefore, when new protocols are implemented, they must supply a reduced radiation dose to the patient (Kumamaru et al. 2016). This can be achieved by deliberating on the CT dose index (CTDIvol), dose length product (DLP), and the diagnostic reference level (DRL). According to Smith-Bindman et al. (2019) CTDvol index considers the average dose value of the slice thickness, while the DLP supplies the measure of CT tube radiation to the patient. Further to this, earlier research shows that dose reference levels vary according to patients, institutions, and countries. However, it was recently suggested that CT protocols and radiation doses have diverse representations worldwide depending on the technical parameters (Smith-Bindman et al. 2019; Vano et al. 2017: 72).

9 Responses to Trauma, Stroke, and/or Intensive Care Patients

Care of the TBI patient does not end in the operating room or resuscitation bay. Admittedly much focus has been placed on the initial management of the trauma patient; consequently, the ICU has received less attention (Shere-Wolfe et al. 2012). TBI requires treatment in an intensive care unit (ICU) in close collaboration with a multidisciplinary team consisting of various medical specialists (Stroker 2019). Mortality is lower in ICU-treated neurological patients (Aguilar and Brott 2011).

Clinical examination remains a fundamental monitoring procedure to identify neurological deterioration and potential indications for surgical interventions (Stocchetti et al. 2017). Conventionally, evaluation of the non-contrast CT images of a possible stroke patient occurs at the scanner console at the time of the acquisition, and findings are directly communicated to the referring physician (Potter et al. 2019). While the initial TBI classification remains typically based on clinical severity, using the GCS coupled with investigation of pupil diameter and reactivity to light.

Time is very critical when caring for these patients because these lesions progress in more than 50% during the first several hours after impact contusion/intracerebral hematoma, either expanding or developing new, non-contiguous hemorrhagic lesions (Stroker 2019). Considering this it is therefore just as critical to note that TBI with associated neural injuries poses an even greater challenge since even mild TBI can blossom into a life-threatening condition when compounded by hypoxia and hypotension. Hence, prevention of secondary injury should be among the highest priories in any patient with evidence or suspicion of CNS injury (Shere-Wolfe et al. 2012). Furthermore, the main determinant of outcome from TBI is the severity of the primary injury, which is irreversible. Thus, it can be concluded that much emphasis should be placed on the type and mechanism of the injury which has an important bearing on the likely course after TBI (Helmy et al. 2007).

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Trauma Imaging Protocols and Image Evaluations

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Abstract

CT is a key imaging modality in the diagnosis of traumatic injuries and stroke. Patients presenting to CT for these clinical indications may pose numerous challenges for the radiographer including the need for rapid imaging and results; a patient's inability to follow commands or be positioned in the standard manner; disease- or treatment-induced alterations in the patient's haemodynamics; non-standard venous access and the potential for a multitude of injuries or diagnoses in a single patient.

This chapter explores CT imaging protocols and procedures for trauma and stroke. Considerations for technique modification in response to the patient's condition and venous access and imaging evaluation for common critical findings in the emergency setting, including solid organ laceration, bladder rupture, and acute brain haemorrhage and infarction, are also discussed.

With a thorough understanding of the principles presented in this chapter, a radiographer may provide crucial support for the timely and accurate assessment of critically ill patients.

Keywords

Trauma imaging · Brain perfusion · Intracranial haemorrhage · Solid organ laceration · Bladder rupture · CT cystogram · Cerebral ischemia · Intraosseous injection

1 Introduction

Trauma can be roughly divided into two categories: polytrauma and isolated trauma. Polytrauma describes an event that results in injury to multiple body regions while an isolated trauma injury is confined to one particular part of the body. The nature of the force applied to the body (whether blunt or penetrating, weak or strong, low or high speed) as well as the direction of the force, the body impact site and personal characteristics of the victim (e.g. age, weight, health status) will influence the type of injuries the patient may sustain (Eid and Abu-Aidan 2007).

Younger patients who suffer polytrauma are more likely to have been involved in high-energy traumas such as a major motor vehicle accident (MVA) or a fall from a considerable height (Leichtle et al. 2019). Older patients may sustain multiple, serious injuries from relatively minor incidents such as a fall from standing or low speed motor vehicle or bicycle accident (de Vries et al. 2018).

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Risks for multiple and/or serious injury include (de Vries et al. 2018; Hildreth et al. 2012; Leichtle et al. 2019):

- High-speed motor vehicle accident.
- Other markers of serious motorised vehicle accident, such as death of another passenger within the same compartment, rollover, full or partial ejection from the vehicle, and intrusion.
- Pedestrian/cyclist collision with a vehicle with the pedestrian/cyclist being thrown or run over.
- Motorcycle crash at 30 km/h or more.
- Fall from greater than 2 stories or 6 m.
- Haemodynamic instability on arrival to the trauma centre.

2 Head and Spine Injuries

Head and spine injuries are common outcomes of polytrauma. Focal head injuries usually result from the head striking a solid object such as the ground or the steering wheel/windscreen of a vehicle (Fadl and Sandstrom 2019) and include skull fracture, intracranial haemorrhage and diffuse axonal injury (Figs. 1, 2, 3, and 4).

Older patients are more likely to suffer from a traumatic brain injury (TBI) from polytrauma compared to a younger person (Trauma Victoria 2021); a possible reason for this is that the brain shrinks with age (Fig. 5), and the increased subdural space is vulnerable to haemorrhage (de Vries 2018). Potential signs of TBI include seizure post injury, significant (>30 min) loss of memory of events leading up to the head injury, loss of consciousness and/or several episodes of vomiting post the event, blackened eyes, cerebrospinal fluid or blood leak from the ears, or reduced level of consciousness (National Institute for Health and Care Excellence 2019).

The severity of a TBI can be indicated by a patient's eye opening, verbal and motor responses (Teasdale and Jennett 1974) and is usually described clinically as the patient's Glasgow Coma Scale, or GCS (Institute of Neurological Sciences, n.d.). The Glasgow Coma Scale grades a patient's responsiveness based on their eye opening, verbal and motor responses (Table 1).

CT of the head may be indicated if the patient has any risk factors for, or signs of TBI. Intoxicated patients with lowered GCS but no signs of head injury may not have an immediate CT; instead they may be held in the emergency department for observation until they become clinically sober. The need for CT may then be reassessed before discharging the patient (Trauma Victoria 2021).

Traumatic spine injuries include fracture, facet joint dislocation, intervertebral disc rupture, ligament tear and sprain, cord oedema and cord transection. Motor vehicle accidents are the most common events that lead to spinal injury; falls, assaults and sporting mishaps are also notable contributors (Singh et al. 2014; Young et al. 2019). Spinal injuries are more prevalent in adolescents and young adults, who tend to engage in higher risk activities, and also in the elderly, who are more susceptible to fractures in general due to osteoporosis/osteopenia and have a higher incidence of falls and motor vehicle accidents (Blackmore et al. 1999a; Jabbour et al. 2008; Lomoschitz et al. 2002).

Patients who have undergone blunt trauma are assumed to have a spinal injury until proven otherwise (Stein et al. 2015). Over half of all spinal injuries occur at the cervical level (Young et al. 2019), and neck pain after experiencing even minor trauma is common (Matthews and Arguelles 2015). Rapid assessment of the cervical spine to exclude injury is important because spine immobilisation and/or hard collars can interfere with the management of a patient's airway and can increase intracranial pressure (Como et al. 2009). Consequently, early removal of immobilisation/hard collar in patients without

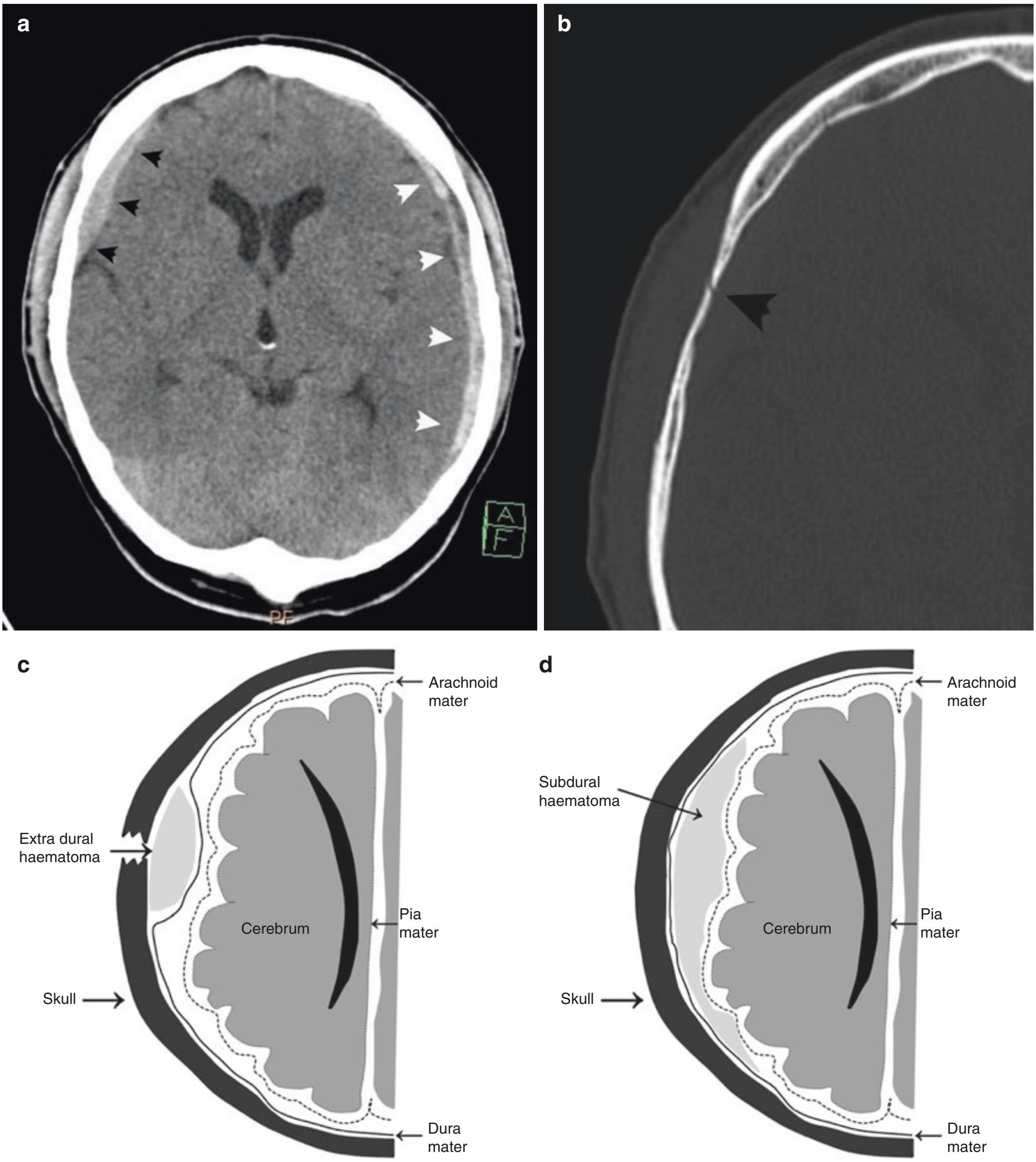

Fig. 1 Traumatic intracranial bleeds: extradural haematoma (EDH) and subdural haematoma (SDH). EDH (**a—**black arrow heads) is commonly associated with a skull fracture (**b—**black arrow head). In the normal state, the extradural space is only a potential space because the dura mater is attached to the inner table of the skull. However, a fracture can cause a tear of the meningeal arteries, and the force of the arterial flow can be great enough to strip the dura away from the bone. An EDH appears as a smooth biconvex haematoma (**c**). Any associated midline shift is usually proportional to the size of the bleed. Because the dura invaginates into the sutures joining the plates of the skull, a SDH will not usually cross a suture line. A SDH (**a—**white arrow heads) is formed from tearing of vessels that bridge the cerebral cortex and the dural sinuses. The haematoma is not confined as with an EDH and therefore it is free to spread widely over the hemisphere, which gives it a wavy concave outline (**d**). SDH is often associated with underlying deep brain tissue damage, which produces oedema. The oedema increases the mass effect of the injury. With SDH, the amount of oedema usually has the most significance for the patient's prognosis. SDH can be seen in all age groups; however, the usual mechanism of injury is different: in babies and infants, the main cause is non-accidental injury; in young adults, it is motor vehicle and motor cycle accidents, while in the elderly they are typically caused by falls. CT may have limitations in showing thin subdural collections against the inner table of the skull; the use of a wider window width can improve their detection

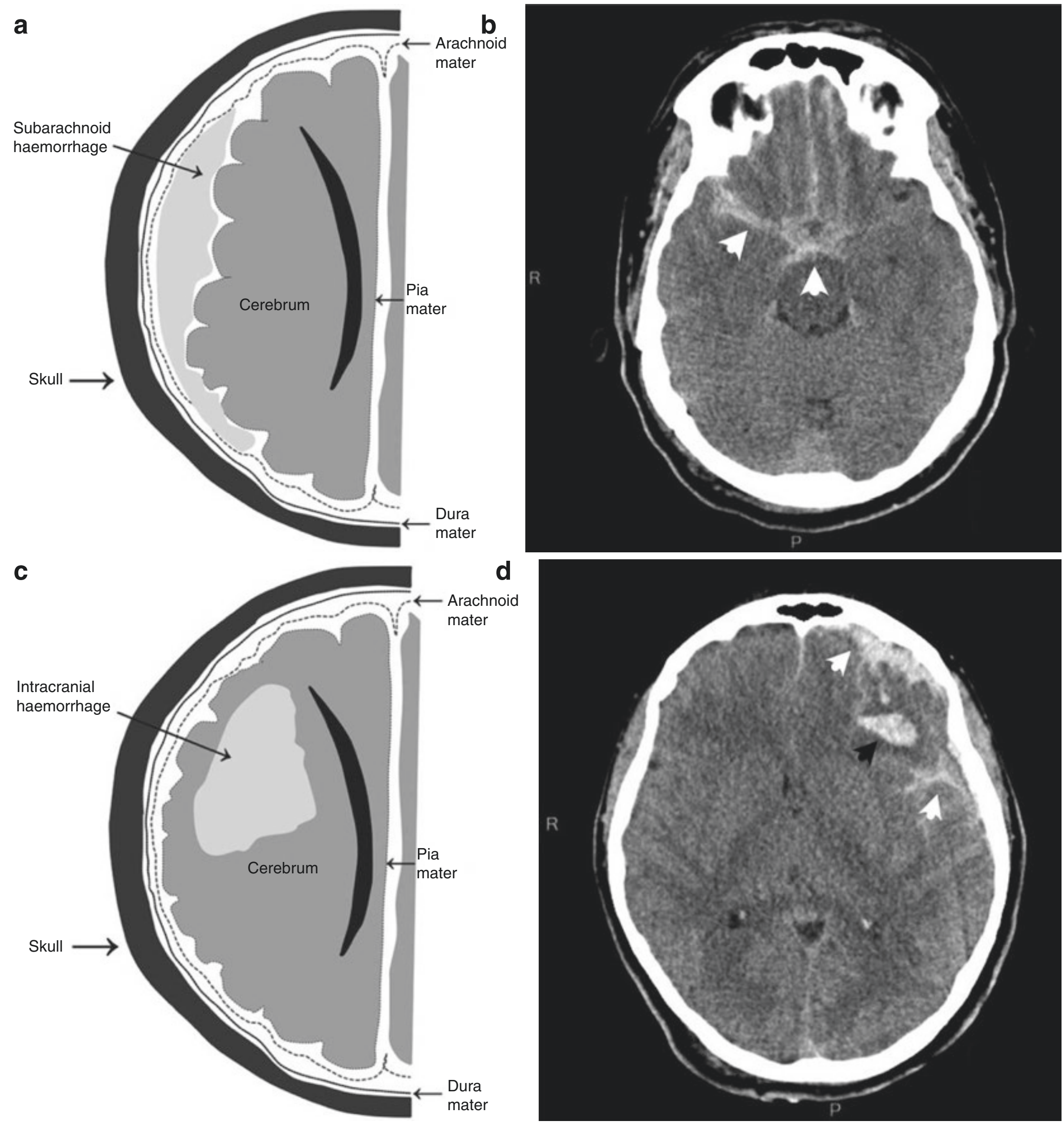

Fig. 2 Traumatic intracranial bleeds: subarachnoid haemorrhage (SAH) and intracerebral haemorrhage (ICH). SAHs are due to injury to the surface veins and arteries on the pia or arachnoid meninges, therefore blood is found within the subarachnoid spaces (**a**) e.g. around the sulci and within the ventricular system (**b—**white arrow heads). Their significance in trauma is usually overshadowed by other findings such as EDH, SDH and/or contusion. An ICH is located within the brain tissue and is due to bruising or contusion of the tissue. In trauma they are often accompanied by other cerebral pathology. (**c**) shows the location of an intracranial haemorrhage. (**d**) shows both ICH (black arrow head) and SAH (white arrow heads) in a 48-year-old female who fell down the stairs

Fig. 3 Traumatic intracranial bleeds: diffuse axonal injury (DAI). DAI is caused by severe trauma and rotational forces, which results in damage to the white matter axons, especially in the midline. They are most commonly seen in high-speed motor vehicle accidents. It is a very serious injury, often with a poor prognosis, yet the CT appearance may be unremarkable. CT signs include diffuse cerebral swelling, loss of grey-white matter differentiation, small foci of haemorrhage and, occasionally, subarachnoid blood (Mesfin et al. 2020)

cervical spine injury is desirable. Imaging all patients who require clearance of the cervical spine would lead to excessive radiation dose and demand on imaging services, so clinical decision rules, for example the NEXUS criteria (Hoffman et al. 1998) and the Canadian C-spine rules (Stiell et al. 2001), are widely used to determine which patients should undergo imaging. Although these clinical decision rules differ slightly from each other, and there is no consensus on which rule optimises the use of imaging, a dangerous mechanism of injury or the presence of focal neurological deficit requires imaging according to most rules. On the other hand, an alert patient without neck pain, focal neurological symptoms or distracting injury, and with a functional range of neck motion can be cleared after a clinical exam only (Stein et al. 2015).

Prior to the widespread availability of wide-coverage multi-slice CT, plain radiographs were routinely performed as the first-line imaging modality for clearing the cervical spine, with CT reserved for when the plain X-ray views were inconclusive or unable to be obtained. However, more recent studies have shown CT to be more sensitive (Mathen et al. 2007), time-efficient (Daffner 2001) and cost effective (Blackmore et al. 1999b) than plain films, particularly considering most trauma patients at high risk for cervical spine fracture already require CT imaging for other potential injuries. Furthermore, advances in CT radiation dose reduction enable current CT systems to provide radiation doses more comparable to those for 3-view X-ray imaging of the cervical spine (Mulkens et al. 2007). Plain X-rays are therefore now generally reserved for the screening of patients at low risk of cervical spine injury (Stein et al. 2015).

CT of the cervical spine is also indicated if an intracranial bleed is demonstrated in a patient who was referred for CT head only after blunt trauma, even if the patient did not meet criteria for cervical spine imaging, due to an increased risk of associated C-spine injury (Thesleff et al. 2017).

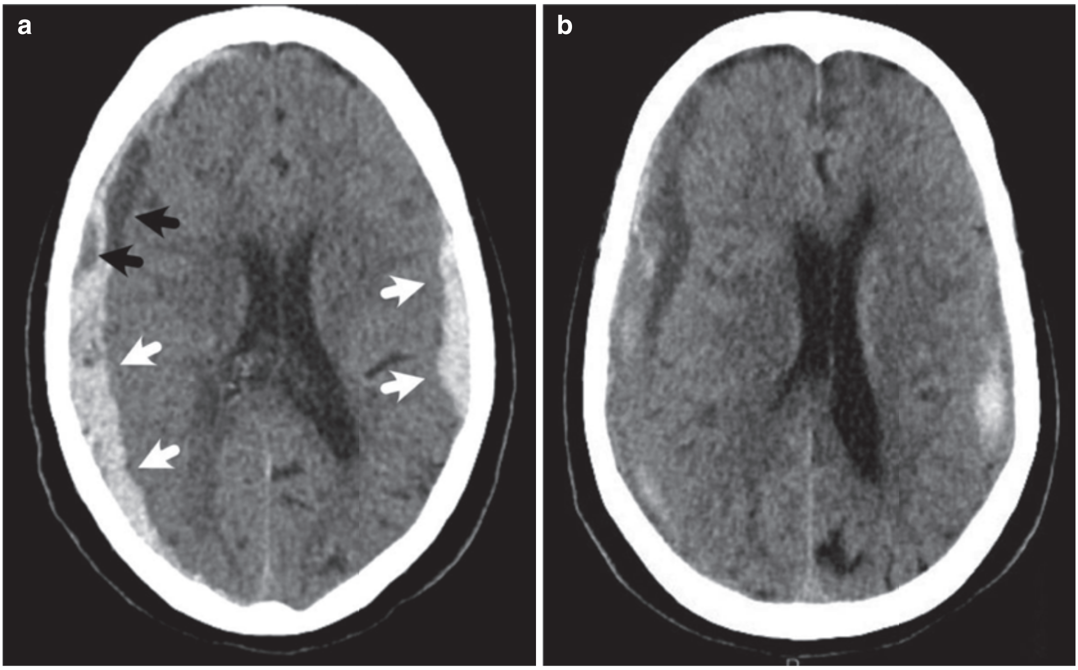

Fig. 4 CT density changes in an evolving intracranial bleed. Bilateral acute subdural haematomas (white arrow heads) in a 70-year-old woman appear mostly hyperdense on first presentation (**a**). There are some low-density components on the right side (black arrow heads), which most likely represent active bleed as non-clotted blood has similar density to brain. 1 week later (**b**), the CT density has reduced; some areas of the haemorrhage now appear isodense compared to the brain, while others are hypodense. Some hyperdense areas remain

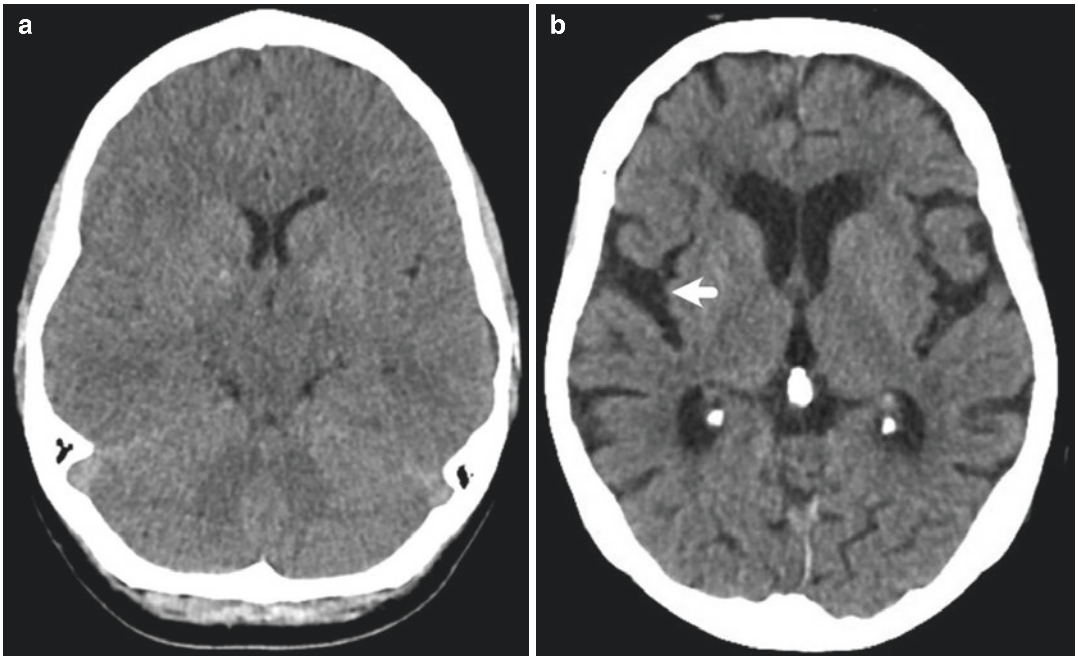

Fig. 5 Age-related changes of the subdural space. Images from the CT head exam of a 15-year-old female (**a**) and a 96-year-old female (**b**). Note the global CSF space prominence in the older woman (white arrow head), reflecting brain volume loss

Table 1 Glasgow Coma Scale

Score	Eye opening response	Verbal response	Motor response
1	No response	No response	No response
2	Opens eyes to pressure (e.g. pressure to the supraorbital notch or trapezius squeeze)	Producing sounds only	Elbow straightens in response to pain (abnormal response to pain)
3	Opens eyes to sound	Produces occasional, unconnected words	Elbow bends (normal response) & wrist bends (abnormal response) to pain
4	Opens eyes spontaneously	Confused	Elbow bends in response to pain (normal response to pain)
5		Orientated with full clear sentences	Only moves limbs in an attempt to remove a painful stimulus (e.g. pressure to the supraorbital notch or trapezius squeeze)
6			Can control limbs on command

The patient's score for each of the three response criteria are added. A fully alert patient with no brain injury will have a GCS of 15. The lowest GCS possible is 3. A GCS equal to or greater than 13 is classified as minor TBI, while a GCS between 9 and 12 indicates moderate brain injury. Severe TBI is classified as GCS less than, or equal to 8. Only the upper limbs are assessed for motor response as lower limb response is an unreliable indicator of brain injury (Adam et al. 2017). GCS may not be a reliable indicator of severity of TBI if the patient is under the influence of drugs or alcohol (Trauma Victoria 2021)

3 Thorax, Abdomen & Pelvis

Blunt trauma to the torso is most commonly the result of a motor vehicle accident or fall from a height (Avey et al. 2006; Mayberry 2000). Severe chest injuries are associated with compression and/or sudden deceleration of the thorax and include pulmonary laceration and contusion, pneumothorax, haemothorax, diaphragmatic rupture and aortic or oesophageal tear (Raptis 2019). Injuries caused by direct force that does not result in deceleration or thoracic compression are generally limited to the soft tissues and minor fractures (Geyer and Linsenmaier 2016).

Chest radiography is the primary imaging tool for minor chest trauma and is routinely performed in major trauma after the secondary assessment of the patient to detect critical injuries such as flail chest, tension pneumothorax and aortic rupture, and to confirm the position of lines and tubes (Geyer and Linsenmaier 2016). MDCT is indicated for polytrauma and significant chest trauma, and in minor trauma if the chest X-ray is abnormal.

The liver and spleen are the most frequently injured abdominal organs (Coleman 2015) and are often associated with lower rib fractures (Raptis 2019). Pelvic or abdominal X-ray may be performed initially to identify markers for severe trauma such as pelvic and chance fractures (Fig. 6). A FAST examination of the abdomen is indicated if the clinical examination of the patient is compromised by the patient’s level of consciousness or distracting bony injuries of the chest or abdomen (Coleman 2015). The primary purpose of the FAST scan of the abdomen is to detect intraperitoneal free fluid, which, in the context of trauma, would be highly suggestive of intra-abdominal haemorrhage (Bloom and Gibbons 2020). CT is warranted if the FAST

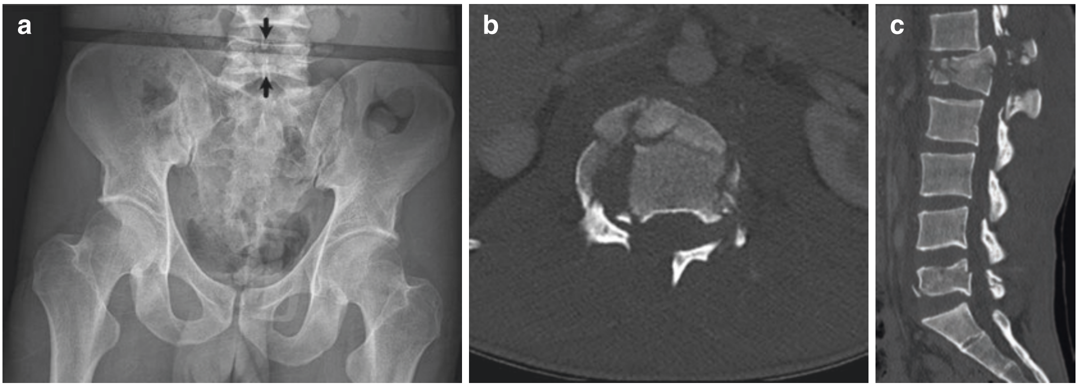

Fig. 6 Chance fracture of the first lumbar vertebra in a 31-year-old male who struck a barricade while riding a motorcycle and was thrown 10 m. (**a**) is a radiograph of this patient, highlighting the location of the fractures (black arrows). (**b**) is an axial lumbar spine CT at L1 vertebra. (**c**) is a sagittal plane of the lumbar spine CT. Chance fractures are caused by a flexion-distraction mechanism, most commonly at thoracolumbar junction, for example flexion over a lap seat belt with a front impact motor vehicle collision. They are an unstable fracture because they involve all three spinal columns, and they are associated with an increased risk of bowel injury (Grossbach et al. 2013, Hayes et al. 1991). The fracture is visible as a loss of vertebral height (arrows) on the screening pelvic X-ray that was performed soon after the patient's arrival in the emergency department. The subsequent trauma CT scan shows a comminuted fracture through the body, pedicles and laminae of the L1 vertebrae (**a**, **b**) with retropulsion into the spinal canal (**c**). The patient also has fractures of the L2 and L5 vertebra (**c**)

exam is positive and the patient is haemodynamically stable, or if the FAST scan is negative but there are clinical signs of intra-abdominal injury, such as abdominal distension or seatbelt sign (Coleman 2015).

Diagnosis of pelvic fractures from polytrauma is critical as pelvic fracture has high risk of morbidity and mortality from blood loss. A pelvic fracture itself can be responsible for considerable blood loss, but pelvic fractures are also frequently associated with blood loss from other serious or life-threatening injury, including head injury, solid organ laceration and aortic tear (Demetriades et al. 2002). Pelvic fractures as a result of a fall more frequently result in pelvic bleeding only, while pelvic fractures sustained from a polytrauma event are often associated with additional blood loss from other injuries (Montmany et al. 2015).

Bladder rupture is an uncommon but significant injury associated with pelvic fracture (Hertz et al. 2020). Clinical predictors of bladder rupture include wide (>1 cm) diastasis of the pubic symphysis or sacroiliac joints, or fracture of the pelvic ring with associated displacement >1 cm, in combination with high red blood cell count on urinalysis or gross haematuria (Avey et al. 2006) (Fig. 7).

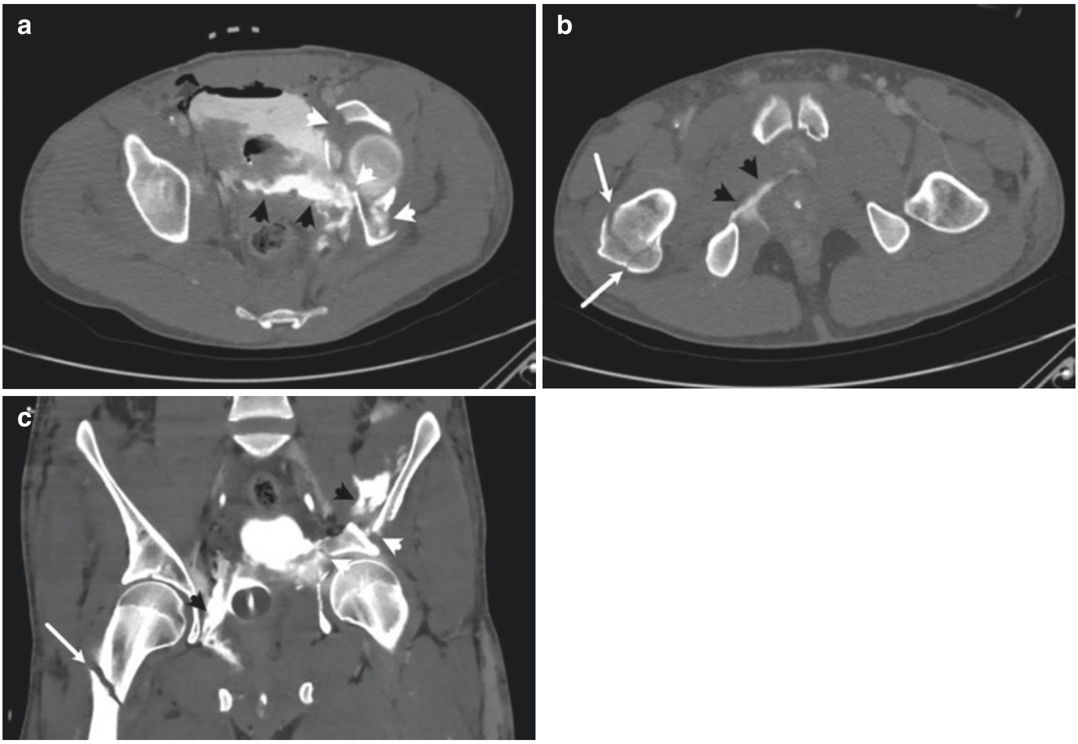

Fig. 7 Axial (**a**, **b**) and coronal (**c**) images of bladder rupture in a 22-year-old male involved in a motor vehicle collision with a tree. The patient had been transferred from a regional hospital due to the severity of his injuries. The CT performed at the tertiary hospital shows multiple pelvic fractures (white arrow heads) and extravasation of contrast from the bladder (black arrow heads), indicating rupture. The patient also has a fractured right femur (**b**, **c** white arrows)

4 Penetrating and Vascular Injuries

Penetrating trauma is most commonly associated with stabbings, shootings, explosive devices and the use of cutting or piercing tools in the workplace or home (e.g. nail gun). The strength of the force by which the penetrating object enters the body influences the type and location of injuries sustained. Low-velocity penetrating trauma results in damage to the organs along the trajectory only, whereas pressure waves triggered by high-velocity projectiles can cause blunt injuries further afield (Chand 2019). High-velocity penetrating trauma invariably causes both vascular and organ injury (Wahlberg and Goldstone 2017a).

Penetrating trauma is the most common mechanism for vascular injury (Lateef Wani et al. 2012; Wahlberg and Goldstone 2017b); however, blunt trauma can also result in damage to arteries and/or veins. In the neck, dissection of the carotid artery, although rare, is the most frequent outcome, and high-speed MVA the main cause of blunt vascular injury (Fusco and Harrigan 2011). Neck hyperextension and rotation appear to be a major mechanism of blunt injury to the neck vessels (Fadl and Sandstrom 2019). The vertebral arteries are less prone to injury overall as they are protected from direct impact by the cervical vertebrae (Wahlberg and Goldstone 2017a); however, they are more vulnerable than the carotid arteries in the setting of subluxation and/or fractures of the upper cervical spine (Fassett et al. 2008).

In the chest and abdomen, blunt traumatic vascular injuries can result from direct compression, for example compression of the aorta against the spine by the sternum or steering wheel during a motor vehicle accident or by rapid deceleration

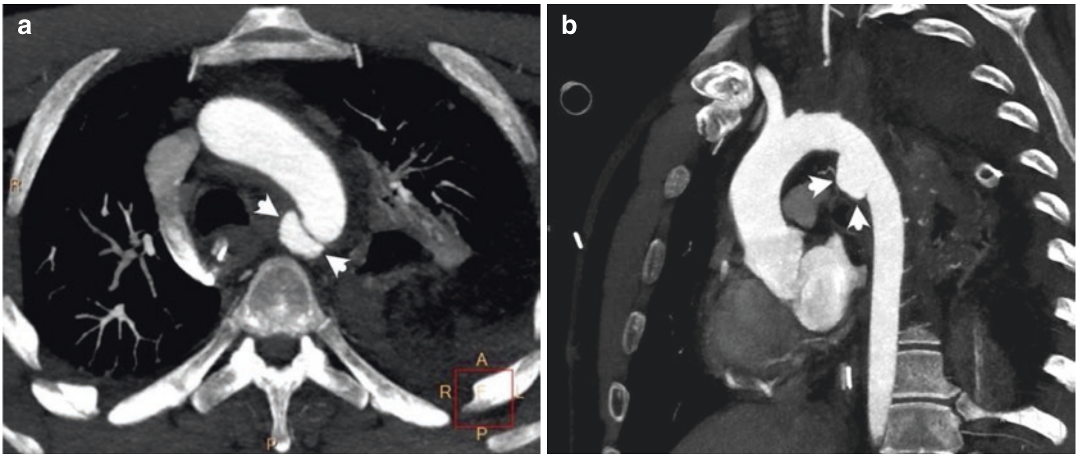

Fig. 8 Axial (**a**) and oblique sagittal (**b**) maximum intensity projection (MIP) images of a traumatic aortic pseudoaneurysm due to intimal tear in a 39-year-old male involved in a motorcycle accident. A pseudoaneurysm is an abnormal dilatation of the outer wall (tunica adventitia) of a blood vessel that occurs when the inner layers of the blood vessel (the intima and tunica media) rupture. The blood is contained with the outpouching (white arrow heads) (Eisenberg 2019). This patient had multiple other injuries, including left diaphragmatic rupture, high-grade contusion of the caecum and ascending colon, liver laceration and pseudoaneurysm of the left vertebral artery

(Fadl and Sandstrom 2019; Geyer and Linsenmaier 2016). Compression forces tend to cause intimal tears and intramural haematoma, while deceleration can cause stretching and twisting of vessels at points of attachment (Wahlberg and Goldstone 2017b). Major vascular injuries are usually found in conjunction with damage to multiple organs, such as the liver, pancreas and bowel (Fig. 8). Prehospital mortality is high with blunt aortic trauma. Patients who do reach care in time are often in shock and highly unstable (Neschis et al. 2008); consequently, they are frequently taken straight to the operating theatre without CT imaging.

5 Extremities

Injuries to the extremities may not be assessed during an initial polytrauma CT examination to expedite diagnosis and treatment of life-threatening head, neck and torso injuries. However, in some instances an injury to an extremity may require immediate intervention, so an urgent CT may be requested to evaluate the extent of injury and/or to plan surgical treatment, for example fracture/dislocation with compromised blood flow or traumatic amputation.

6 CT Imaging of Trauma

A full body polytrauma scan on a 64-slice or greater MDCT typically covers from the vertex to below the symphysis pubis (Dreizin and Munera 2012). Depending on the volume coverage of the CT and institution preference, the scan may be acquired as separate exposures of the head, neck, chest and abdomen, or as a reduced number of combined scans. The individual components of a polytrauma protocol are explained below:

Head: A non-contrast scan of the head is mandatory to assess for intracranial haemorrhage because the presence of intravenous contrast can mask bleeds, which, when new, appear hyperdense (Fig. 4). Bone reconstructions of the skull are standard. To avoid unnecessary movement of the neck, polytrauma patients are usually not positioned with their head in the head rest. Additional exposure may therefore be required to penetrate the thicker table top and maintain image quality. With the patient in this position, the face will usually be included within the scan range for the head (Fig. 9). Dedicated multiplanar +/− 3D reformats of the face can thus be reconstructed if the patient has signs of facial trauma, or if a facial fracture or significant soft tissue injury is identified on the head images.

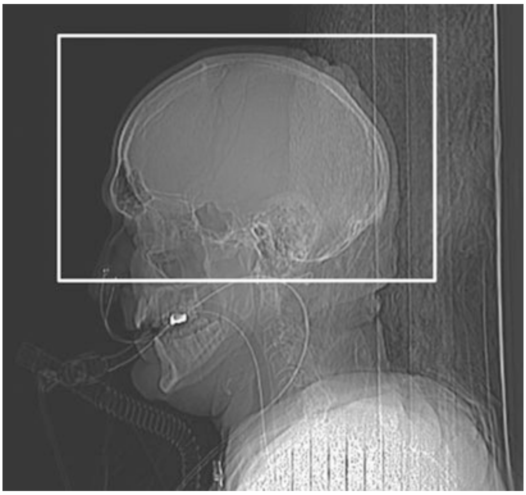

Fig. 9 Typical head position for a multitrauma patient. The patient will often be scanned with their head on the tabletop. In this position, the scan range for the head scan will usually include most of the face

Cervical spine: The cervical spine may be acquired by various means; as a separate non-contrast scan; as a continuation of the head scan; or reconstructed from a CT angiogram of the neck. CTA protocols often use higher pitch than that for a dedicated cervical spine scan; thus, the bony reconstructions from the angiography data may have insufficient spatial resolution to detect subtle fractures. However, this is less of a problem with current wide-coverage MDCT and this method reduces radiation dose by eliminating the dedicated cervical spine scan. In combined non-contrast head and cervical spine acquisitions, care is required to ensure adequate exposure for the brain while avoiding overexposure of the spine. Dose modulation, a standard feature on most MDCT systems, is very effective for adjusting dose relative to patient density where constant noise levels are required. However, brain CT requires lower image noise compared to spine CT; thus, if the acquisition is set to achieve the lower noise level for the head, standard dose modulation would result in excess radiation to the neck. If, on the other hand, the noise level for dose modulation is set to that for the spine, the brain would be underexposed. Some MDCT scanners allow the setting of different image quality levels across a single acquisition; if this feature is available, a single acquisition of the head and cervical spine may be preferred as it would avoid scan overlap at the base of skull/upper cervical spine. Soft tissue reconstructions of the cervical spine using a large enough field of view to extend to the pharynx anteriorly and the skin margin posteriorly should be included because swelling of the soft tissues may be the only CT indicator of a fracture or unstable ligamentous injury (Friesen and Brownlee 2014).

CT angiogram: CT angiography of the chest and abdomen is indicated for high-risk mechanisms of injury (Dreizin and Munera 2012). Minimum coverage is from the lower neck (to demonstrate the origins of the major neck and upper limb vessels) to below the solid abdominal organs, e.g. liver, kidneys, spleen (as these are prone to laceration and haemorrhage). The superior scan limit may be extended to the Circle of Willis if the mechanism of injury puts the patient at risk of carotid or vertebral injury. A separate CTA of the neck is not required with 64-slice or greater MDCT as sensitivity of an extended body CTA is equivalent to that of dedicated CTA neck for trauma (Sliker et al. 2008). If a pelvic fracture is demonstrated on the screening pelvis X-ray or on the CT scanogram (Fig. 10), the CTA can be extended to the symphysis pubis to allow for assessment of active bleeding in the pelvis.

Portal venous abdomen ± pelvis: Lacerations of solid organs such as the liver, kidneys and spleen are best demonstrated on portal venous phase imaging. This phase also helps to distinguish between pseudoaneurysm and active bleeding and provides some clues to the rate of bleeding, which can be estimated by the volume of extravasated contrast (Dreizin and Munera 2012) (Figs. 11 and 12). If the CT angiogram included the pelvis, the portal venous phase may extend from the diaphragm to just below the solid organs, although a full portal venous scan from the diaphragms to symphysis pubis is commonly performed. Oral contrast is not required (Skinner and Driscoll 2013).

Delayed phase: Delayed phase imaging, acquired 3–5 min after the arterial phase scan is indicated for significant renal trauma to assess for disruptions to the ureters and renal collecting

Fig. 10 Pelvic fractures visible on the anteroposterior (AP) scanogram for a trauma CT (arrow heads). In this patient, the CT angiogram was extended to the symphysis pubis to assess for pelvic bleeding

system and to distinguish between urinoma and haematoma (Iacobellis et al. 2020) (Fig. 13).

CT cystogram: Indications for CT cystography include gross haematuria, free intraperitoneal or peri-vesical fluid or a pelvic ring injury (Fadl and Sandstrom 2019). The preferred CT cystography technique involves retrograde filling of the bladder with 250–350 ml of 3–5% iodinated solution via gravity-drip infusion (Joshi et al. 2018). A delayed CT of the bladder performed after a contrast-enhanced scan is not recommended unless there is suspected urethral injury contraindicating the insertion of a Foley catheter because this method does not produce very high bladder pressure, and injuries may be missed if the bladder is not sufficiently distended (Urry et al. 2016; Wirth et al. 2010).

Thoracic and lumbar spine reconstructions: Dedicated thoracic and lumbar spine CT is not necessary as reconstructed views from the CT angiogram and/or portal venous abdomen scan using targeted field of view and bone algorithm have high sensitivity and specificity for the diagnosis of spine fracture (Shah and Ross 2016). Reconstructions of the whole spine are particularly important when a vertebral fracture is identified at any stage of the trauma CT examination as approximately 10% of patients have concomitant spinal fractures in another spinal column

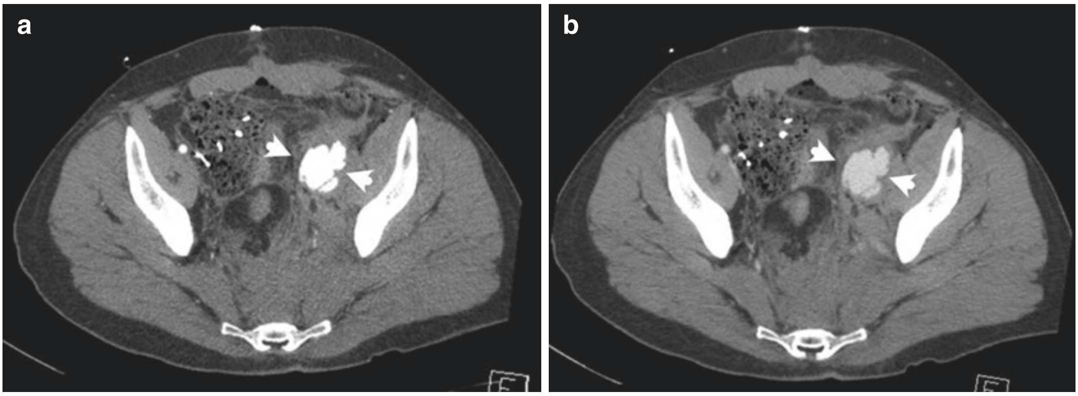

Fig. 11 Traumatic arteriovenous fistula and pseudoaneurysm of the left external iliac artery and left external iliac vein in a 37-year-old male who was shot in the thigh. There is no change to the distribution of the contrast between the arterial (**a**) and portal venous (**b**) phases, indicating the blood is contained

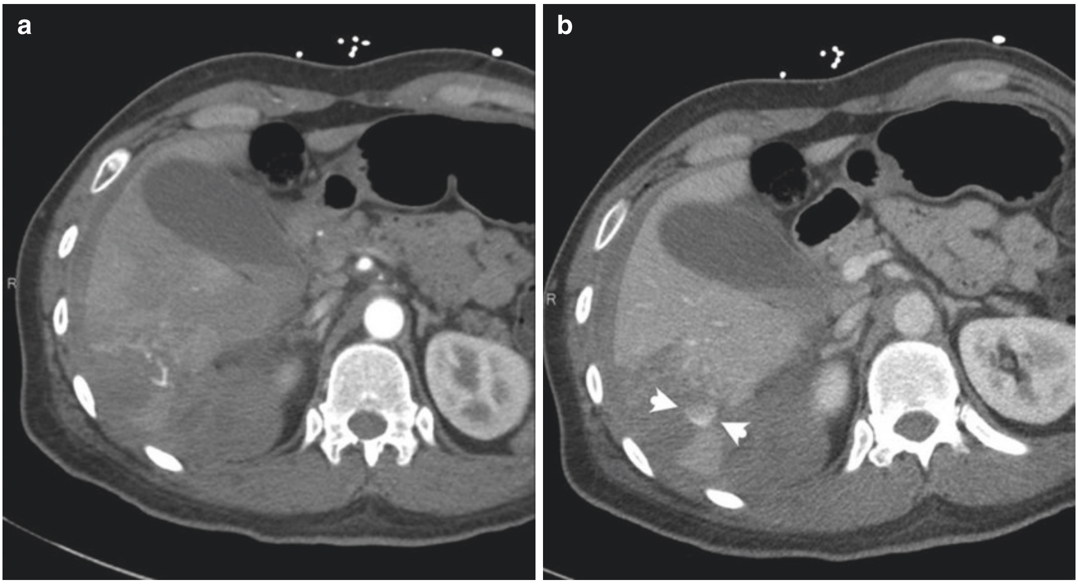

Fig. 12 Active bleeding with pseudoaneurysm formation within the posterior right hepatic lobe in a 43-year-old male who was involved in a high-speed motor vehicle accident. The portal venous phase (**b**) shows an increase in accumulated contrast (arrow heads) compared to the arterial phase (**a**), indicating active bleed

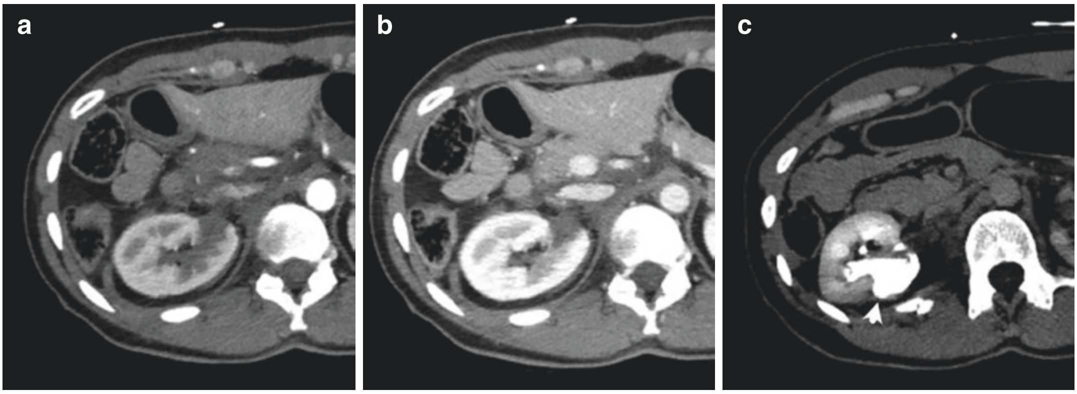

Fig. 13 Renal laceration with extension into the renal hilum in a 47-year-old patient involved in a motor vehicle accident. The arterial (**a**) and portal venous phases (**b**) did not demonstrate active bleeding. Five-minute delayed scan (**c**) demonstrates extravasation of contrast into the retroperitoneal space (arrow heads), indicating rupture of the collecting system

(Wang et al. 2015; Hanson et al. 2000; Young et al. 2019) (Fig. 14). Sagittal and coronal multiplanar reconstructions improve the detection of axially orientated fractures and better demonstrate transverse and spinous process fractures and retropulsion of bone fragments into the spinal canal (Dreizin and Munera 2012).

Volume-rendered reconstructions: Three-dimensional rendering of the CTA chest data to show the rib cage with the shoulder girdles and high-density foreign objects such as tubes and lines electronically removed provides important information about rib fractures for not only clinical management, but also for legal and forensic reasons (Geyer and Linsenmaier 2016) (Fig. 15). Volume-rendered reconstruction of the pelvis or spine for significant fractures can provide important spatial information to assist surgical planning (Dreizin and Munera 2012) (Fig. 16).

The principles outlined above for CT imaging of polytrauma can also be applied to specific anatomical regions affected by isolated trauma.

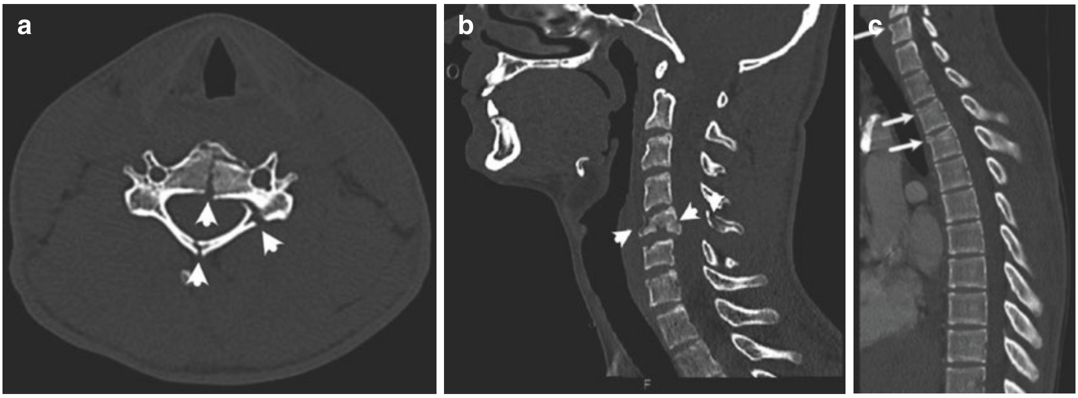

Fig. 14 Trauma scan on a 19-year-old male involved in a high-speed motor vehicle accident demonstrates an unstable burst fracture of C5 (**a** & **b** white arrow heads). The patient also had compression fractures of C7, T3 and T4 (**c** white arrows)

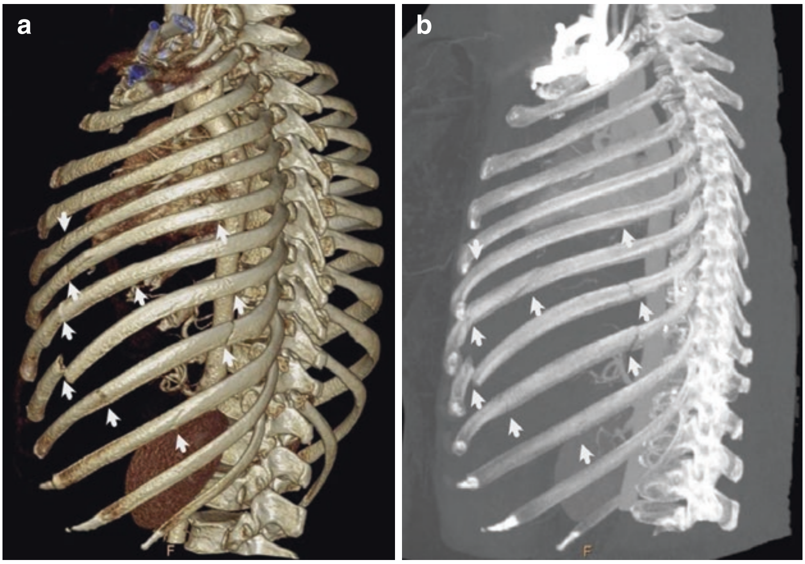

Fig. 15 Volume-rendered (**a**) and maximum intensity projection (MIP) (**b**) reconstructions of the ribs in a 43-year-old female post fall. Ribs 5–10 had obvious fractures (arrow heads), and there were possible fractures in ribs 2–4. Some of the lower ribs were broken in two places, indicating a radiological flail segment. The term flail chest is used when 3 or more contiguous ribs have been fractured in two or more places. The fractured rib segments move paradoxically with the chest during respiration, i.e. when the patient breathes in, the rib cage expands but the flail segment moves inwards, and when the patient breathes out, the rib cage deflates but the flail segment moves outwards (Kaewlai et al. 2008). Flail chest indicates significant trauma. This patient had multiple other injuries, including haemothorax, and liver and splenic lacerations

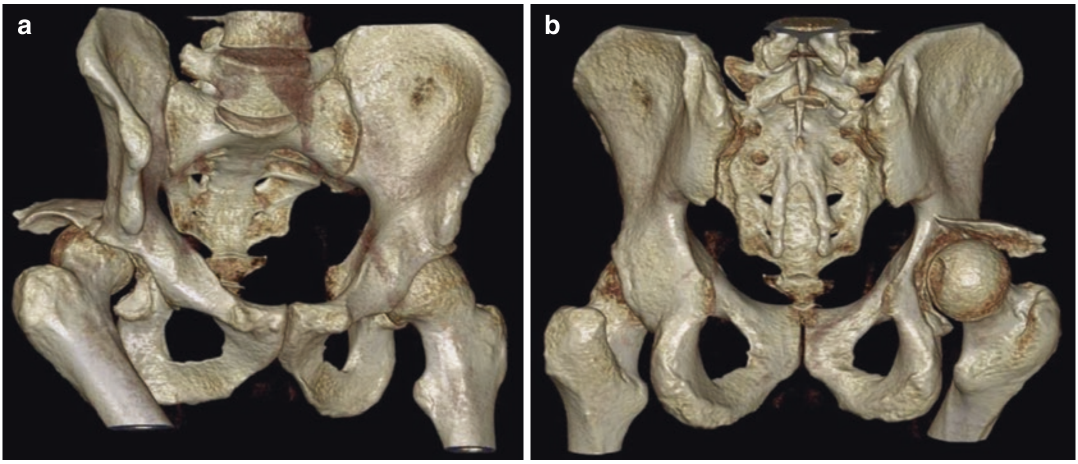

Fig. 16 Volume-rendered reconstruction of the pelvis viewed anteriorly (**a**) and posteriorly (**b**) in a 40-year-old male who had fallen from 5 m. The patient underwent surgical reconstruction of his right acetabulum

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Stroke Imaging Protocols

Karen Dobeli

Abstract

A stroke occurs when blood flow to a portion of the brain is suddenly interrupted. Strokes can arise when a cerebral artery is blocked by a blood clot (ischemic stroke) or when there is spontaneous rupture of a blood vessel within or on the surface of the brain (haemorrhagic stroke). When the blood supply to part of the brain is cut off during a stroke, the brain tissue normally supplied by the affected artery can survive for some time because it can receive blood from collateral blood vessels. The rate of death of brain cells is determined by the volume and speed of delivery of blood supplied by the collateral circulation, which is extremely variable. Brain tissue that receives sufficient perfusion from the collateral vessels is more responsive to treatment and more likely to return to normal function if the obstructed artery is recanalized (opened). However, brain cells with poor collateral blood are more susceptible to further injury during treatment (e.g. haemorrhage) and are more likely to die (infarct), resulting in permanent brain damage.

Keywords

Stroke · Intra-arterial thrombectomy · Decompressive hemicraniectomy · CT perfusion · Consultant radiographer

1 Introduction

There are various treatments for stroke, depending on the type, size, location and cause of the stroke as well as the time elapsed between the event and the patient presenting to the emergency department. Immediate treatment for ischemic stroke includes:

Intravenous thrombolysis: Patients receive intravenous injection of a clot-busting drug (commonly Alteplase, also known as t-PA or rt-PA). This treatment is most effective when given within the first few hours after the stroke and has better outcomes for recanalizing small distal cerebral arteries (Konstas et al. 2009a; Menon et al. 2013; Menon et al. 2015a). The success rate for large arteries such as the internal carotid and proximal middle cerebral arteries is relatively low (10–30%) (Lee et al. 2007). Thrombolysis is contraindicated for haemorrhage stroke and for patients at risk for bleeding. Up to 7% of ischemic stroke patients without bleeding risk who receive IV Alteplase will develop intracranial haemorrhage (Yaghi et al. 2017).

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Intra-arterial thrombectomy (clot retrieval): This procedure is performed in the angiography suite by specialist neuro-interventionalists. A catheter is navigated to the site of the arterial blockage in the brain, and the clot is mechanically removed or dissolved with intravenous thrombolytics (Chung et al. 2013). Although only 1 in 10 patients are eligible for thrombectomy, the chances of a good therapeutic outcome in patients who undergo the procedure are increased by more than 50% (Goyal et al. 2016). Thrombectomy is usually performed in combination with intravenous thrombolysis.

Decompressive hemicraniectomy: Occlusion of the middle cerebral artery can result in significant brain oedema, which increases intracranial pressure and poses a risk of small blood vessel compression, leading to cell death in parts of the brain not originally affected by the stroke. Decompressive hemicraniectomy is a life-saving procedure, in which the skull overlying the side of the stroke is removed and the dura is opened to release intracranial pressure. The procedure is usually performed within 48 hours of a stroke (Świat et al. 2010).

An estimated 1.9 million neurons die every minute a stroke remains untreated (Stroke Association 2018); thus, rapid diagnosis of stroke is of paramount importance. CT is the initial and major imaging modality involved in the diagnosis of stroke because it is fast and readily available, it can detect mimics for stroke such as tumour and subdural haemorrhage, and it can provide critical information required to determine the most appropriate treatment for the patient (Shetty and Lev 2005).

A basic CT stroke protocol (Table 1) consists of a non-contrast scan (NCCT) of the head and a CT angiogram (CTA) of the head and neck. The NCCT serves several purposes:

- To rule out haemorrhagic stroke or other cerebral bleed (Fig. 1).
- To rule out other causes for the patient's symptoms and to demonstrate long-standing brain abnormalities, which may aid the interpretation of brain perfusion imaging.
- To confirm ischemic stroke: CT is not particularly sensitive for detecting ischemic stroke within the acute treatment window because changes to the brain do not produce large differences in CT attenuation compared to unaffected brain until days or weeks later. However, an acute stroke may be suspected if there is loss of grey-white matter differentiation in the basal ganglia or cortical or insular ribbons (Barrett and Meschia 2013) (Fig. 2). Occlusion of the middle cerebral artery (MCA) may be obvious on NCCT as a hyperdense ribbon called the 'hyperdense MCA sign' (Barrett and Meschia 2013) (Fig. 3). This sign is best appreciated on thin slice (<2 mm) images (Mair et al. 2015).

The CTA can be performed using an institution's standard protocol for CTA of the head and neck, extending from the aortic arch to the skull vertex (Rudd et al. 2017). This coverage demonstrates the level of arterial obstruction in the brain, can provide information on the quality of collateral flow (Fig. 4), allows assessment of underlying causes for stroke in the neck (e.g. carotid artery atherosclerosis or dissection) and provides anatomical information about the origins and tortuosity of the neck vessels, which aids the planning and performance of endovascular clot retrieval (Byrne et al. 2017). Because rapid decisions are critical in stroke, post-processing should be kept to a minimum, for example standard thin slice axial images and thick slice axial maximum intensity projection (MIP) reformats only.

A potential pitfall of the CT angiogram is slow blood flow in the major arteries on the same side as the stroke. Thus, the level of the occlusion may appear to be more proximal than it really is (Lev et al. 2001), which may cause delays in a clot retrieval procedure because the selection of approach and catheters is made for the incorrect level (Chung et al. 2013). If a vessel appears to be occluded on the CTA, a repeat scan from just below the level of the perceived occlusion to the vertex (with no additional contrast) can confirm the true level of the occlusion (Chung et al. 2013).

The basic CT stroke protocol can be supplemented by specialized CT stroke techniques, namely multiphase CTA, and/or CT perfusion.

Table 1 Stroke protocol

Patient position	Head first, supine, arms down. If performing CT perfusion: tilt the chin down to position the glabellomeatal line as parallel to the gantry as possible. Immobilize the patient well.	
Topogram	AP and lateral to include mid chest to the vertex.	
Non-contrast head	**Scan region**	Foramen magnum to skull vertex
	Contrast	N/A
	Breath hold	N/A
	Recons	Axial, sagittal and coronal MPRs.
CTA head and neck	**Scan region**	Pre-monitoring: Aortic arch Main acquisition: Aortic arch to vertex. Notes: • May be performed in the cranio-caudal direction to reduce venous contamination. When using this technique, the pre-monitoring scan can be positioned at the level of the mandible. • If using a very wide coverage CT unit, the CTA head may be obtained from the CT perfusion acquisition; thus, the CTA can be limited to coverage of the neck.
	Contrast	50–75 ml of low or iso-osmolar non-ionic intravenous contrast administered by power injector at 4–5 ml/s, followed by 40–50 ml of normal saline injected at the same rate.
	Breath HOLD	N/A
	Recons	For rapid image reconstruction and diagnosis, reconstructions can be limited to: • Thin, overlapping axial MPR • Thick, overlapping axial MIP, e.g. 10@5
	Delayed scans (if multiphase CTA is used instead of CT perfusion)	Perform 1 or 2 scans of the brain at 8–12 s intervals after the completion of the CTA head and neck. No further contrast is required. Reconstructions can be limited to thick, overlapping MIP.
CT perfusion	**Scan region**	8 cm or greater slab with the inferior extent level with the base of the pituitary fossa.
	Contrast	30–50 ml of low or iso-osmolar non-ionic intravenous contrast administered by power injector at 6–8 ml/s, followed by 30–50 ml of normal saline injected at the same rate.
	Breath hold	N/A
	Recons	• Thick (5–10 mm) axial reconstructions (thickness may be determined by the postprocessing perfusion software to be used).

Two features of stroke that have important implications for treatment, particularly thrombolysis, are the ‘core’ and ‘penumbra’. The core of a stroke describes brain tissue that is irreversibly damaged, while brain tissue that is damaged but can potentially be salvaged through treatment is called the penumbra. Collateral supply to the damaged brain is the key difference; tissue within the penumbra has good collateral supply, while poor collateral supply usually indicates non-salvageable tissue (Menon et al. 2015a). Multiphase CTA and CT perfusion can both provide information about perfusion of the brain tissue via collateral circulation. Evidence suggests addition of either of these techniques to the standard stroke protocol increases confidence with decision-making on thrombectomy (Khumtong et al. 2020).

Multiphase CT is a simple examination; it involves two repeat CT scans of the brain immediately following the CTA of the head and neck. The delay between the CTA and the first repeat, and between the first and second repeats is quite short, about 8–12 s (Byrne et al. 2017). The delayed scans can be reconstructed as thick slab

Fig. 1 This 86-year-old female was brought to hospital by ambulance with stroke symptoms. She was immediately transferred to the imaging department for a CT stroke exam. The non-contrast scan demonstrates a large, left cerebellar haemorrhage (white arrow heads) with extension into the cerebral ventricles (black arrow heads). A CT angiogram was performed, which showed an aneurysm of the left posterior inferior carotid artery (PICA). The patient was then taken to the angiography suite for coiling of the aneurysm

Fig. 2 Non-contrast scan of the head on this 48-female (Patient X), who woke with right-sided facial droop, expressive dysphasia and right-sided weakness shows subtle loss of grey-white matter differentiation involving the left insular cortex, left lentiform nucleus and left caudate nucleus (ellipse)

MIPs as for the CTA to enable easy comparison of the three arterial scans and reduce processing time. When the three arterial phases are viewed side-by-side, the rate and amount of collateral circulation to the ischemic area can be compared to the unaffected side (Fig. 5). Regions of infarcted (core) tissue and penumbra can be estimated, which can help determine which patients would benefit from early treatment (Menon et al. 2015b). The multiphase CT protocol also improves the localization of occlusions for the same reason a delayed CT does (Byrne et al. 2017).

CT perfusion is based on the principle that after an injection of iodinated contrast, the CT density within a tissue is directly related to the amount of contrast contained within that tissue. CT perfusion is performed by scanning the brain at regular intervals after the injection of iodinated contrast. The images are loaded into postprocessing software, which measures the CT density in Hounsfield units (HU) of each pixel in every image within the scan volume for each scan acquisition and plots the HU values against time to create a time-density curve for each pixel. Because contrast is delivered to the tissue via the blood, these curves can provide information about the volume of blood that is delivered to each voxel of the brain represented by the pixels, as well as how quickly the blood passes through each brain voxel (Khumtong et al. 2020; Ramalho and Fragata 2014). The results demonstrate the perfusion of the brain tissue and, importantly for stroke, which tissue may be salvageable and which may not.

Accuracy of the CT perfusion calculations relies on:

- A compact contrast bolus and high level of contrast enhancement in the brain (Konstas et al. 2009b).
- Adequate sampling (scanning) rate to generate precise time-density curves.
- Measurements across the entire first pass contrast bolus transit time through the brain tissue

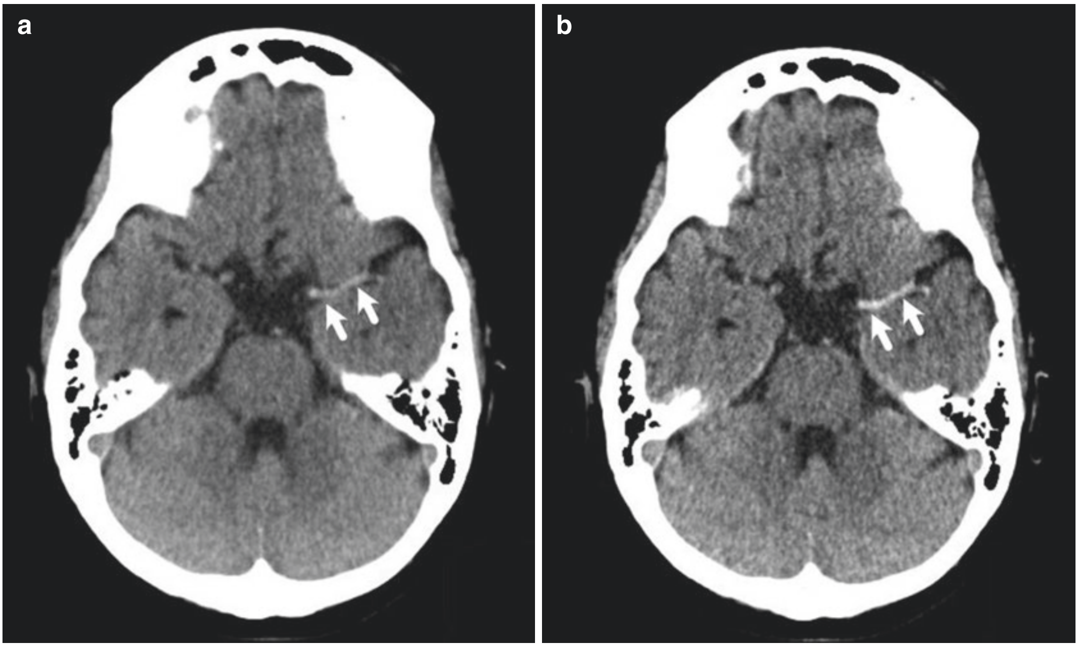

Fig. 3 5 mm (**a**) and 2 mm (**b**) thick images of the non-contrast CT brain from Patient X. There is a hyperdense MCA sign on the patient's left (arrows). There is greater contrast difference between the MCA and the surrounding brain on the thinner slice (**b**)

Fig. 4 Coronal maximum intensity projection (MIP) from the head and neck Patient X demonstrating absent left middle cerebral artery enhancement (arrow) and collateral supply to the ischemic area of the brain (arrow heads)

(i.e. from just before the contrast first reaches the brain tissue through the arteries, to just after it passes out of the brain tissue via the veins).

A typical CT perfusion protocol consists of rapid injection (e.g. 6–8 ml/s) of 40–50 ml of high-concentration iodinated contrast (e.g. 350 or 370 mg I/ml) followed by a 20–40 ml 'saline chaser' via power injector through a wide bore (e.g. 18 gauge) venepuncture catheter in a large vein (e.g. antecubital vein) (Konstas et al. 2009b; Khumtong et al. 2020). The perfusion scan series is initiated 3–5 s after the start of the contrast injection, and scans are acquired every 1–3 s for 60–90 s. To reduce radiation dose while providing for accurate time-density curves, scans may be acquired at short intervals during the arterial phase but at longer intervals during the venous outflow stage. Although the contrast bolus transit time may be relatively short (e.g. 35 s) in many

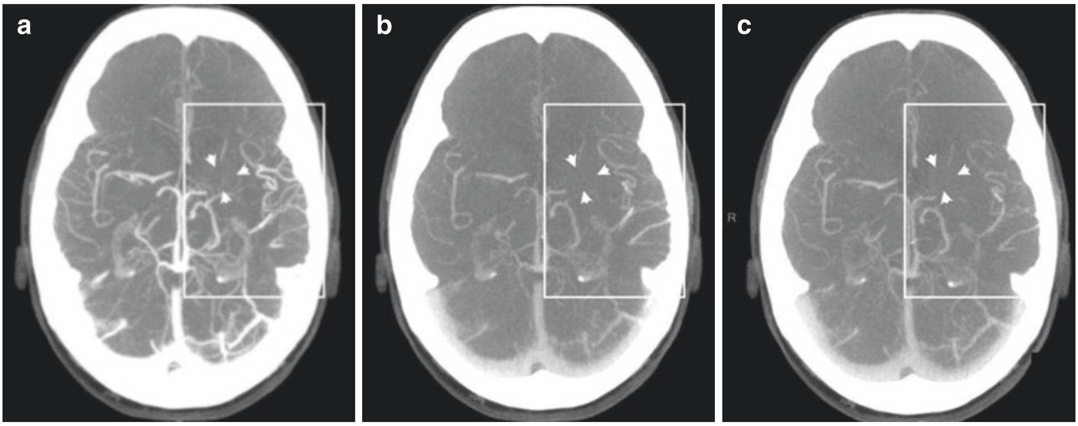

Fig. 5 Thick slab MIPs from the head and neck CTA (**a**), 8 s delayed scan (**b**) and 16 s delayed scan (**c**) of Patient X. There is collateral supply to the majority of the left middle cerebral artery territory (box); however, there appears to be a small region that does not show arterial enhancement across all three scans (arrow head)

patients, extended scanning is often required because some patients with stroke may have delayed flow due to arterial occlusion or poor cardiac output (Konstas et al. 2009b).

The brain perfusion scan can be performed after the CT angiogram or prior to it. If performed after, a delay of 3–5 min is required to allow the contrast from the angiogram to reach equilibrium within the brain.

The volume of brain coverage for CT perfusion is highly variable across different scanner makes and models. Some CT units provide full brain coverage through wide detector coverage, fast helical shuttle (continuous helical scanning as the table moves quickly in and out), or jog mode (non-helical scanning with fast movement between two table locations). Others are only able to provide limited coverage; however, if extended coverage is required, two separate contiguous perfusion scans can be performed with a delay of 3–5 min in between. The most important anatomical areas to be included within the perfusion scan range are the basal ganglia, internal capsule, and more distal territories supplied by the middle cerebral artery as these are the most common sites for stroke (Hui et al. 2020).

To reduce radiation dose to the lens of the eyes, and to include as much of the critical brain regions within the scan range, the patient's head can be tilted with the chin down to position the glabellomeatal line (GML) as parallel to the gantry as possible (Fig. 6). Immobilization of the patient's head is very important for CT perfusion postprocessing, as motion within or between scan acquisitions can reduce the accuracy of the results or even make it impossible to obtain the perfusion information, and patients who have suffered a stroke are often confused and disorientated (de Lucas et al. 2008).

Perfusion scans are acquired at low tube voltage (e.g. 80 kVp) and low tube current; radiation doses from CT perfusion are in the order of 3.5–5 millisieverts (mSv) (Konstas et al. 2009b; Lev et al. 2001; Menon et al. 2015b; Wintermark and Lev 2010). Data are reconstructed in thick slices (e.g. 5–10 mm) to provide adequate contrast-to-noise and signal-to-noise ratios.

After reconstruction, the CT perfusion images are loaded into dedicated post-processing software. Typically, initial processing involves subtraction of the skull, and corrections for any motion (Konstas et al. 2009b). Perfusion calculations require identification of an artery (e.g.

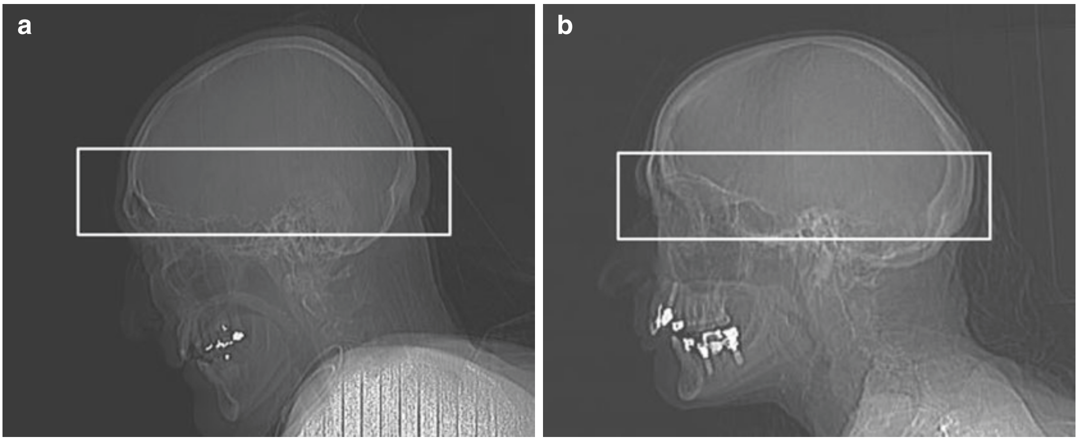

Fig. 6 Head positioning for CT perfusion. (**a**) Ideally, the head should be tilted forward to position the base of skull as parallel to the gantry plane as possible as this will increase the amount of brain at risk that lies within the scan plane. If the patient's head is tilted backwards (**b**), some of the territory of the anterior cerebral artery will be excluded

anterior cerebral) and a vein (e.g. superior sagittal sinus), for which time-density curves are created (Fig. 7). The time-density curves are analysed using mathematical techniques to generate parameters that describe perfusion. Commonly used perfusion parameters to assess ischemic stroke are (Carroll et al. 2008; Konstas et al. 2009a; Ramalho and Fragata 2014):

- Cerebral blood volume (CBV): This is the total volume of blood in a given volume of the brain.
- Cerebral blood flow (CBF): This is the volume of blood flowing through a given volume of the brain tissue per unit of time.
- Mean transit time (MTT): This is the average time in seconds it takes for blood to move through a given volume of brain tissue. MTT = CBV/CBF.

In infarcted (non-salvageable) tissue, there is little, if any, perfusion of the injured brain tissue from collateral vessels. Thus, the blood flow (CVF) and blood volume (CBV) will both be low. In potentially salvageable tissue, the brain tissue will be receiving sufficient blood volume from the collateral arteries (normal, or even elevated CBV), but the delivery of blood will be slower (reduced CBF). In both infarcted tissue and salvageable tissue, the MTT will be longer compared to normal brain tissue.

Two other perfusion parameters frequently used are time to peak (TTP) and Tmax. TTP is the time from the first scan to when enhancement in the arterial input reaches maximum HU (Ramalho and Fragata 2014; Wouters et al. 2017). Tmax is the time between the contrast reaching the arterial input to when it reaches the brain tissue. Longer TTP or Tmax indicates delayed flow, for example due to thrombus. Tmax is more complex to calculate but it is better at accounting for delayed flow due to other factors, such as poor cardiac output (Calamante et al. 2010; Wouters et al. 2017).

Colour maps are assigned to the perfusion parameters to provide visual display of areas of abnormal perfusion. Infarct core and penumbra can also be highlighted, based on user-selectable values (Fig. 8).

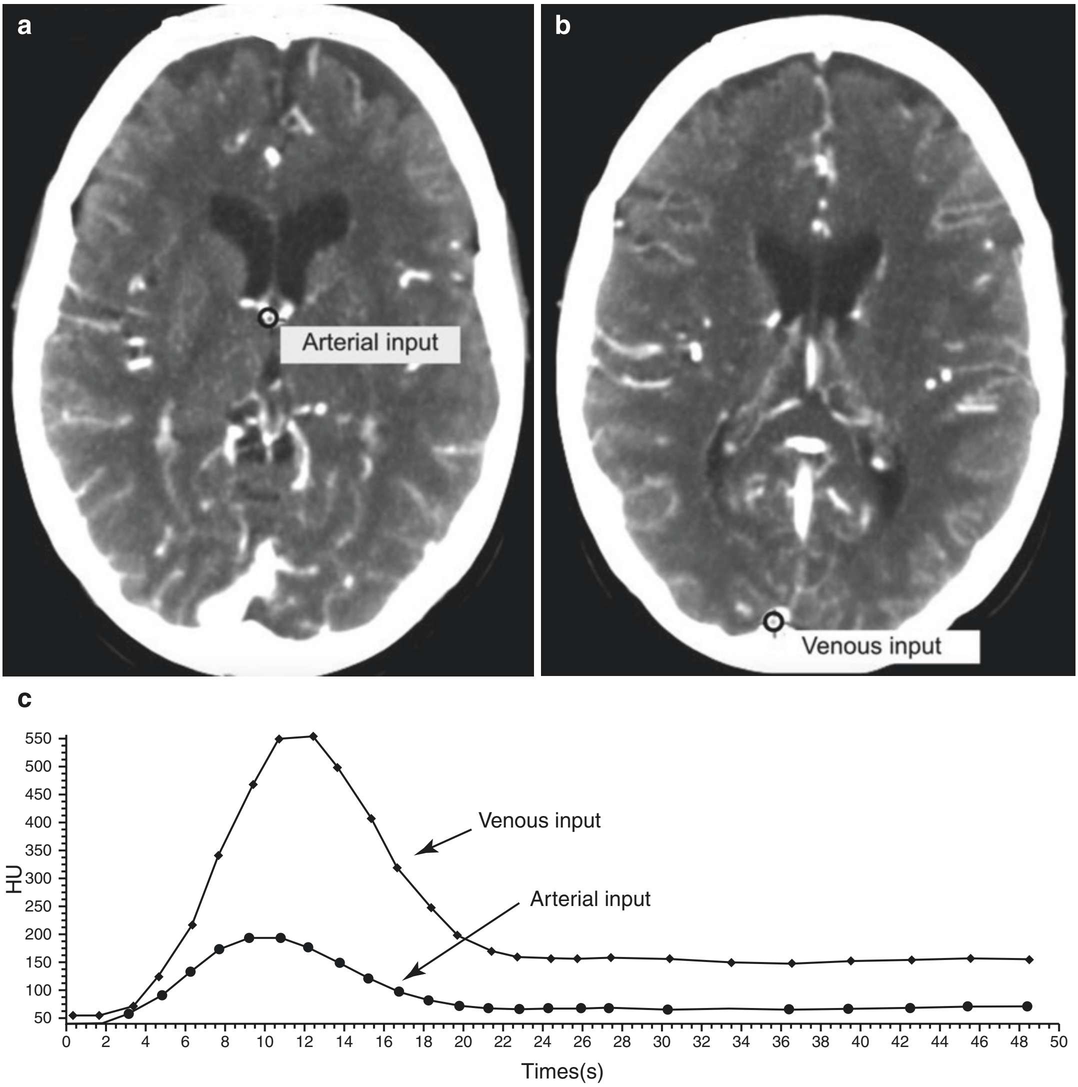

Fig. 7 Arterial and venous inputs for CT perfusion calculations for Patient X. The anterior or middle cerebral artery on the unaffected side is typically used for the arterial input (**a**), while the posterior superior sagittal sinus is often used for the venous input (**b**). Time-density curves are created for these inputs (**c**). The venous curve should have a higher, but later peak than the arterial curve

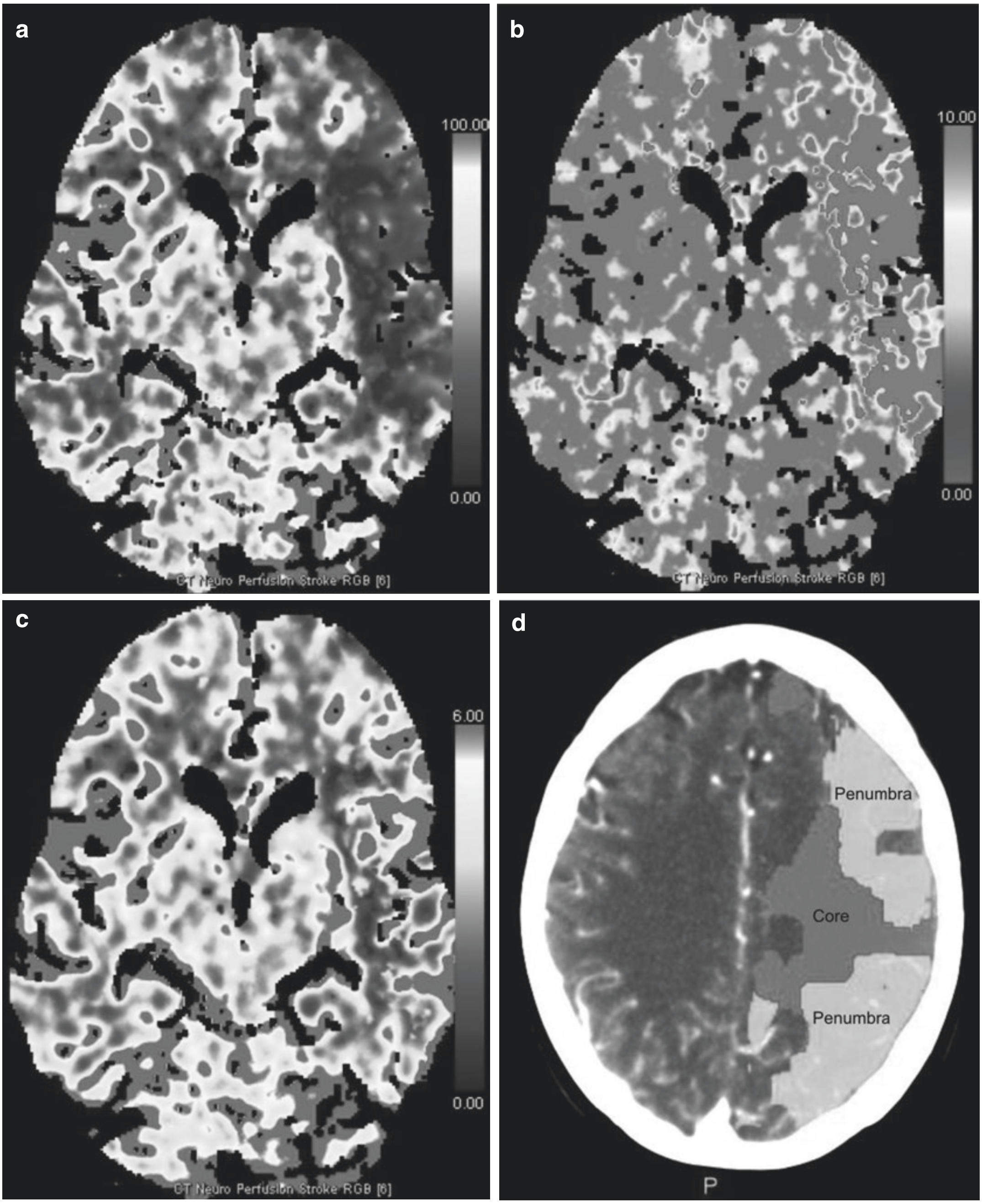

Fig. 8 Perfusion maps for Patient X. There is decreased cerebral blood flow (**a**) and increased mean transit time (**b**) in the region of the middle cerebral artery (MCA) on the patient's left. The cerebral volume map (**c**) suggests increased blood volume in the distal MCA territory, which is a normal phenomenon believed to be caused by dilatation of veins in the hypo-perfused region (Konstas et al. 2009b). Thresholds for perfusion parameters can be set in most CT perfusion post-processing software, which allows the creation of core/penumbra summary maps. The summary map for Patient X (**d**) suggests a large infarct core even though the CBV map does not seem to demonstrate reduced CBV in this region. Patients with a large infarct core are at higher risk of haemorrhagic stroke transformation (Bivard et al. 2015)

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Responses to Trauma and Stroke

Karen Dobeli

Abstract

In major trauma, replacement of blood and body fluids is vital to patient survival. However, attaining venous access in a patient who has suffered significant blood loss can be difficult. Intraosseous (IO) access is an alternative method for obtaining vascular access in such patients. In this method, a large gauge needle is inserted into the bone marrow space, usually of a long bone such as the tibia, femur or humerus. The medullary cavity has a rich network of blood vessels, which can quickly deliver injected fluids to the central vascular system. IO contrast media injections can be made using a power injector with injection rates up to 4 ml/s. Confirming the position of the intraosseous device before administering IV contrast is recommended, as is a small test injection of saline to check the injection pressure, because these devices are often inserted by first responders in the field and there is a risk of dislodgement as the patient is moved between the field, ambulance, emergency department and CT scanner.

Keywords

Trauma imaging · IV contrast · Alternate positioning · Alternate technique

1 Introduction

Although patients with significant blood loss have usually been stabilised with fluid resuscitation before coming to the CT department, their haemodynamics may still be abnormal (Leidel et al. 2010; Winkler et al. 2017; Elwan et al. 2017). Using a standard CTA injection protocol can result in poor contrast opacification because patients may have excess fluid, which dilutes the contrast, and/or reduced cardiac output, which affects contrast transit times (Fig. 1). A dedicated major trauma injection protocol which uses a larger volume of (high-strength) contrast and a higher injection rate can reduce the risk of 'washed out' contrast. Determination of the appropriate scan start time can be made through a test injection or bolus tracking; bolus tracking is quicker to perform than a test injection so is preferable for trauma imaging.

Radiation dose for a full body polytrauma CT is relatively high, being in the order of 20–30 mSv (Gordic et al. 2015), which falls into the dose range reported to increase the risk of certain cancers (Australian Radiation Protection Nuclear Safety Agency n.d.). However, the principle of 'risk versus benefit' must be applied, and considering the high potential for multiple serious injuries, the radiation dose will be justified for patients who have individual risks for polytrauma (such as advanced age) and/or have experienced a high-risk mechanism of injury. Furthermore, the

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use of CT as the primary imaging modality may improve survival rates for polytrauma patients due to its ability to rapidly screen for a wide spectrum of injuries from the head to the toes (Huber-Wagner et al. 2009). On the other hand, careful consideration of the benefit of a full polytrauma CT should be made for young patients with lower risk injury mechanism and without strong clinical suspicion of serious injury.

Lower dose protocols that combine arterial and portal venous enhancement phases for trauma imaging of the chest and abdomen have been developed and reported in the literature. The specifics of the contrast injection protocol and scan delay vary between institutions but overall there are two main methods: split bolus and long injection time. The split bolus technique essentially combines a portal venous abdomen injection with an arterial injection. The portal venous contrast volume makes up the first phase of the injection; a pause follows so that the second (arterial) phase of the injection commences about 40 s after the injection is first started. The scan is performed at approximately 60 s (Beenen et al. 2015). In the long injection time method, contrast is injected at a low infusion rate (e.g. 2 ml/s) so that contrast is still present in the arterial system when the scan is performed at the standard portal venous delay (Eichler et al. 2015). These techniques reduce radiation dose by eliminating the overlap from the diaphragm to the iliac crests/symphysis pubis between the arterial and portal venous phase scans. However, there is some concern regarding the ability of a single pass trauma protocol to detect vascular injuries due to reduced intraluminal contrast density (Iacobellis et al. 2020).

Attention to patient position and preparation of the scan region can also reduce radiation dose. Most MDCT scanners feature automatic exposure, which adjusts the standard protocol dose based on patient density measurement from the scout scans. The patient's arms should be lifted above their head whenever possible when imaging the torso because this will reduce radiation dose and avoid streak artefact, which may otherwise obscure solid organ haemorrhage (Iacobellis et al. 2020) (Fig. 1). If the patient's arms cannot be abducted, improved image quality can be obtained by lifting and supporting the patient's elbows so they are no longer in the same horizontal plane as the spine (Fig. 2). High-density objects such as metal clamps, oxygen cylinders and ECG control boxes should also be positioned outside the scan field.

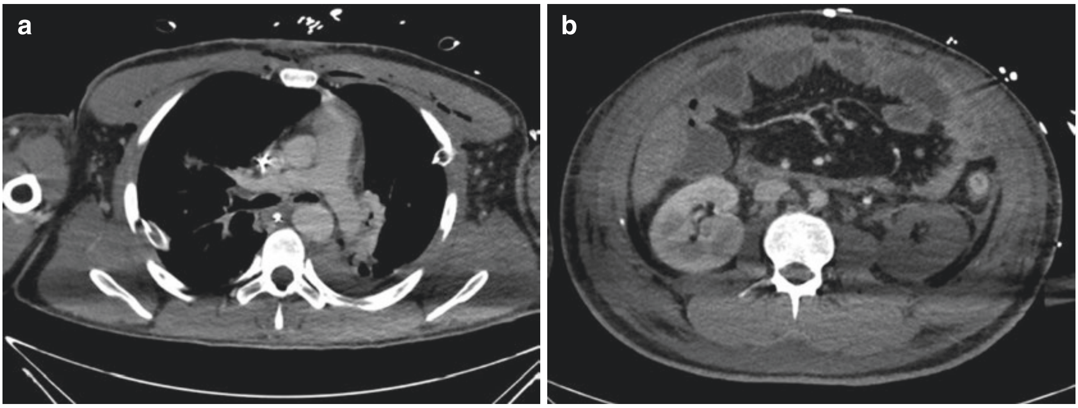

Fig. 1 Poor contrast enhancement in a 23-year-old male who was involved in a motorcycle accident in a regional area. (**a**) CT Chest. (**b**) CT Abdomen/Pelvis. He was stabilised at a local hospital before being airlifted to the closest tertiary level hospital. The patient had suffered significant blood loss and was given aggressive fluid resuscitation. Note the loss of definition in the abdominal musculature and apparent increase in CT density of the extra abdominal fat, which are indicators of high fluid load. These images also demonstrate horizontal streak artefact, which is caused by the patient's arms lying by their side. There is increased X-ray absorption when the X-ray tube is in the 3 o'clock and 9 o'clock positions because the long bones of the arms lie in the same plane as the spine

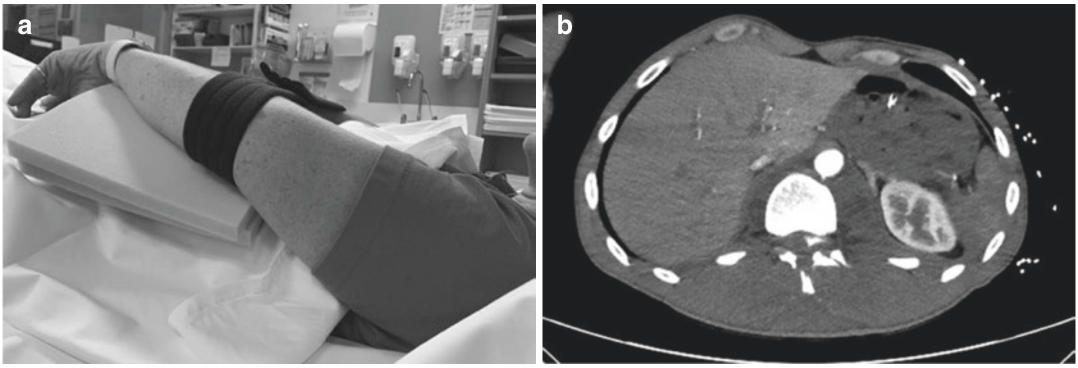

Fig. 2 Alternate positioning of the arms if they are unable to be raised above the patient's head. Lifting the elbows off the table with the use of pads and straps to raise them above the level of the spine (**a**) can reduce streak artefact through the kidneys, spleen and liver (**b**)

Patients with stroke or head injury may be confused and agitated. However, delaying the examination or sedation of the patient may not be desirable. In these circumstances, the following techniques could be considered in conjunction with the use of the scanner's immobilisation devices such as straps and cushions:

- Elimination of the scout scans to reduce overall scan time. This technique voids the use of dose modulation and can lead to underscanning, which risks missing important findings and/or negating the time saving by having to repeat the scan, or over-scanning, which increases patient radiation dose. Consequently, this technique should only be considered for CT of the head because the required scan extent is easily determined from external anatomical landmarks and CT of the brain is less dependent on dose modulation to balance radiation dose with image quality.
- Modification of the CT technique to reduce the scan time. Significantly reducing the scan time can be achieved by increasing the pitch and/or using the shortest rotation time and/or the highest kVp. This will usually result in a low-quality scan through reduction of projection data and/or exposure; however, image quality can be sufficient to rule out major pathology. This technique is also best suited to CT of the brain and can be used in combination with the 'no scout view' method explained above. A dedicated 'fast' head protocol could be set up on the scanner for quick access if the situation arises.
- Scanning the patient however they are comfortable. Patients, particularly elderly ones, may be uncomfortable lying supine on the CT couch. Alert patients can verbalise this and request to change position, but patients with reduced consciousness may not be able to. Instead, they attempt to reposition themselves to a more comfortable position, and because they are also not able to understand commands, they often move while the scan is in progress despite the radiographer asking them to keep still. Placing a pillow under the patient's knees, and/or soft padding under the buttocks or shoulders, can be all that is required to achieve patient compliance, particularly for emaciated patients. Placing very restless patients on their side is often effective as this is comfortable for patients with back pain and it is easier for many patients to breath on their side compared to on their back. This technique requires attention to how the patient's position is entered into the scanner when registering the patient as the scanner software will assign left, right, anterior and posterior based on this information.

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Whole-Body CT

Elio Arruzza and Shayne Chau

Abstract

Trauma is a leading cause of death globally. Early and accurate diagnosis in the emergency department (ED) is crucial in maximizing health outcomes for trauma patients. The utilization of Computed Tomography (CT), owing to its superior imaging capabilities and rapid scanning speeds, has significantly increased in recent years in the initial assessment of these patients. A protocol which surveys the entire head, thorax and abdomen in a single scan, fittingly named 'Whole Body CT' (WBCT), has been recently implemented in many centres as a way of reducing mortality and time spent in the ED/hospital. Aside from these possible advantages, the obvious risk sourced from excessive exposure to radiation makes a controversial topic. This chapter will exhibit the many facets pertaining to the viability of WBCT for trauma patients in the ED setting, with exploration of its advantages, drawbacks and implications for radiographers.

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1 Background & History

Trauma takes the life of 4.4 million people every year, accounting for 8% of global deaths (World Health Organisation 2021). This is more than the combination of fatalities resultant from HIV/AIDS, malaria and tuberculosis. For every fatality, several thousand more people are injured, leading to emergency department (ED) visits and long-stay hospitalizations, sometimes resulting in permanent disabilities and necessitating long-term healthcare and rehabilitation.

In Australia particularly, over eight million presentations were made to public hospital emergency departments in 2017–2018. Of these numbers, roughly 61,000 individuals were categorized as resuscitation patients, needing to be treated immediately (Australian Institute of Health and Welfare 2018). These presentations have included: (1) motor vehicle accident, motor bike accident, (2) pedestrian crossing, (3) accidental falls, (4) exposure to inanimate mechanical forces, (5) exposure to animate mechanical forces, (6) exposure to electric current/smoke/animals/nature, (7) accidental poi-

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soning, (8) intentional self-harm, (9) assault, (10) complications of medical and surgical care, (11) acute respiratory infections including influenza and pneumonia, (12) intestinal infectious diseases, (13) hypertensive disease, (14) ischaemic heart diseases/ STEMI, (15) out of hospital collapses and (16) cerebrovascular diseases (Pointer 2018). When a patient who has experienced trauma arrives to the emergency department (ED), two components of healthcare are required to provide the most optimum health outcome that the patient is provided the correct diagnosis, and that the diagnosis is made quickly. Regrettably, misdiagnosis and time delay are two of the greatest barriers inhibiting patient survival and quality of life thereafter.

Conventionally, diagnosis of trauma patients presenting to the ED is informed by the Advanced Trauma Life Support (ATLS) protocol, which emphasis the principle of treating first what is likely to kill first (Kool and Blickman 2007). The radiological component of the guidelines encompasses a combination of fast and priority-based physical examination, plain X-ray of the chest and pelvis and focused assessment with sonography for trauma (FAST) (American College of Surgeons 2018). Though these modalities offer little or no radiation doses and are relatively inexpensive, their low diagnostic accuracies for severe injuries mean that CT of selective body regions is often called upon. Using the ATLS has resulted in missed injuries and delayed diagnosis in up to 39% of cases, with even higher rates observed in the more severely injured (Beal et al. 2016).

Since its inception in the early 1970s, CT has evolved to become the cornerstone of imaging hemodynamically stable trauma patients that present to the emergency department (Tsutsumi et al. 2017). ED physicians continually depend on CT's ability to rapidly diagnose life-threatening conditions; so much so, that from 1995 to 2007, the number of ED visits featuring a CT scan increased from 2.7 million to 16.2 million, a near six-fold increase (Larson et al. 2011). In terms of patient dose, it is estimated that CT is responsible for approximately three quarters of the effective radiation dose delivered from all imaging procedures (Fazel et al. 2009). More recently, international increases in CT use in the ED have been reported in Canada, Taiwan, South Korea and Australia (Maxwell et al. 2021).

Global uptake of CT has necessitated and correlated with the rapid advancement of imaging technology, particularly entailing faster scan times, 3D reconstruction capabilities and dose reduction. Initial scanners offered inferior image quality and acquisition times, leading to poor diagnostic accuracies and unreliability in the time-dependent environment of the ED. CT's now dominance in these areas has accelerated since the advent of multi-slice CT in 1998 (Wang et al. 2019). Concurrently, the use of whole-body CT (WBCT) has spawned and developed from the need to rapidly evaluate and treat patients in the ED.

WBCT, which is interchangeably used with the terms 'pan-scan', 'full-body CT' (FBCT) or 'total-body CT' (TBCT), is generally defined as a CT scan of the head, cervical spine, chest, abdomen and pelvis. Though WBCT has become a more widely used part of the trauma evaluation protocol in many centres internationally, its use is a highly debated topic in the field of radiology and emergency medicine. This is principally due to the radiation dose imparted during a single scan, though other aspects like potentially excessive cost and the promotion of self-referred WBCT to screen healthy patients during the early 2000's (Berlin 2003) have undoubtedly added fuel to the fire. A plethora of methodologically sound studies have been performed demonstrating both advantages and drawbacks of WBCT in the trauma setting. A breakthrough article by Weninger et al. (2007) discovered a clear and substantial time benefit in favour of WBCT over conventional protocols. Positive findings were echoed by Huber-Wagner (2009) which supplemented their findings of more rapid time spent in the ED, with an increase in the probability of survival in patients who received a WBCT scan compared to those who received no CT scan or a selective CT scan.

2 Time

Much like the phrase ‘time is brain’ for stroke patients, time plays a crucial role in the context of trauma patients. Prolonged diagnosis and treatment of trauma patients are a contributor to ED overcrowding; inability of the ED to meet the demands for patient triage, medical imaging, pathological testing and specialty consultations, negatively impact the patient flow in ED (Yarmohammadian et al. 2017).

Overwhelmingly, WBCT has been observed to reduce ED times. Palm et al. (2018) followed a substantial sample size of 16,000 patients to demonstrate a significant improvement of approximately 17 less minutes spent in the ED (84.3 vs 67.6). This trend has been reinforced by Hutter et al. (2011) (144.7 vs 83.5), Hong et al. (2016) (186.3 vs 108.6) and James et al. (2017) (459.1 vs 390.9). It is believed that these benefits stem from technological advances relating to acquisition and reconstruction algorithms, which allows rapid acquisition of information from one conclusive scan; as WBCT does not entail time-consumption associated with X-ray and ultrasound, these findings have implications entailing faster diagnosis time for definitive treatment and lessening the impact of ED overcrowding. Furthermore, the approach limits re-evaluation and re-examination procedures, which may also be linked to reductions in overall time spent in hospital, radiation dose and cost of imaging and healthcare over time (Sierink et al. 2016). Reductions in time spent in the ED and hospital permits for rapid clearance of patients with substantial mechanisms of injury who require prompt surgical interventions such as craniotomies and spine procedures, who would otherwise require a lengthy period of observation lengthy and physical examination before entering the operating theatre (American College of Surgeons 2018). A further benefit is that when a WBCT protocol is implemented, alterations in departmental design and CT scanner location are often co-introduced. This was seen in Weninger’s study (2007) which decreased ED time from 104 to 70 min, after patients could be transported directly to the new scanner located in the ED.

In light of these advantages, the link between an alleviation of time spent in the ED and crucial patient-related outcomes is not clear-cut in the context of WBCT. That is to say, it is still inconclusive whether the time saved in the ED by performing WBCT saves more lives compared to conventional protocols. However, where EDs are busy and overcrowded, it is only logical to conclude that such an environment is not conducive to safe, quality and economical healthcare. The impact of high occupancy and limitation of physician access have resulted in increased mortality rates, hospital length of stay (LOS), hospital readmission and even infection transmission rates (Yarmohammadian et al. 2017).

3 Radiation Dose

Like most applications of CT, the most critically opposing argument against more widespread use is excessive radiation dose. Originally and currently where scanners do not possess modern low-dose capabilities, a WBCT scan exposes a patient to greater than 20 mSv of effective radiation dose (Arora and Arora 2019). A dose of 20 mSv will increase the risk of dying from cancer by 1 in 1250 in an average 45-year patients whilst a higher dose of 24 mSv increases this risk by 1 in 900 in a 35-year-old male (Brenner and Hall 2007).

Several studies have compared dose levels of trauma patients experiencing WBCT compared to traditional protocols, and expectedly, these studies indicated lower radiation dose levels for the latter. The starkest discrepancy between WBCT and non-WBCT was discovered by Gordic et al. (2015) which showed WBCT experienced doubled the dose. This is reinforced in other settings which showed an increase in dose of up to a third (James et al. 2017), and the the proportion of patients exposed to a greater than 20 mSv dose increasing significantly (from 19.6 vs 11.6%) after introduction of a WBCT protocol (Asha et al. 2012). Nevertheless, the recent REACT-2 trial by Sierink et al. (2016) suggests that because WBCT may eliminate the need for further imaging, this could potentially lower dose if the entire patient pathway is considered. The trial demonstrated that although dose was higher during the primary survey in the WBCT cohort, doses were more comparable as time proceeded and patients required more scans.

4 Overdiagnosis and Incidental Findings

Incidental findings are a ‘double-edged sword’. On the one hand, they yield a positive impact on future management, providing early diagnosis of pathologies, particularly malignancy or vascular disease. Conversely however, when clinical significance is absent, these findings also result in potentially unwarranted investigations, overexposure to radiation, patient anxiety and excessive costs (Lumbreras et al. 2010). So profound these disadvantages, the term ‘incidentaloma’ has been used to describe incidental findings as a disease in itself. As modern CT produces images of superior quality and by virtue of the vast anatomical region surveyed by WBCT, incidental findings are significantly higher in these scans compared to other modalities. Incidental findings are reported in up to 75% of patients experiencing WBCT, primarily in the abdomen region (Kroczek et al. 2017). In the recent REACT-2 trial, 1 in 24 of findings were found to be a neoplasm pathology, and nearly half of these could have resulted in considerable morbidity.

5 Cost

As controversy surrounding radiation dose continues, and patient-related outcomes like mortality are justifiably prioritized by researchers, limited exploration has been undertaken regarding cost-effectiveness. Furthermore, cost is dependent on several variables based on the individual institution’s capacity to implement and maintain a new protocol, and longer research periods are needed to determine true savings or expenses.

James et al. (2017) discovered that the average cost of hospital stay for a blunt trauma patient at their institution increased by US$4971 after a WBCT protocol was introduced. Conversely, Hong et al. (2016) and Sierink et al. (2016) suggested that cost associated with WBCT was not significantly greater than conventional imaging protocols. In a recent multicentre RCT where trauma patients experienced either WBCT or the ATLS, mean costs of hospital care were €25,809 for the WBCT group and €26,155 (€23,050 to €29,344) the latter, a per-patient and significant difference of €346 in favour of the former ($p = 0.876$) (Treskes et al. 2021).

6 Tips for CT Radiographer When Resuscitation Room Calls

Generally, when a patient arrives to the resuscitation room, the first point of call is the ED consultant requesting an urgent CT to the CT department. Another method may be via a hospital trauma pager system (or via the public announcement throughout the department) with an estimated time of arrival. For instance, the CT radiographer might receive a page noting ‘L1 Trauma ETA 1400’ or ‘pan-scan arriving in 5’.

When the page is sent, an estimated arrival time will be conveyed to the CT radiographer. The radiographer should also be informed whether the patient is intubated or not, and whether the patient is coherent. This information is then communicated to all staff involved, including the radiologist on-site and the nursing staff. If there is only one CT machine in the department, the non-urgent scans or outpatient scans are placed on hold and the room is then prepared for the pan-scan, including preparation of the power/contrast injector, and room set-up for patient transfer.

The second most important component of the process is patient consent. The CT radiographer should note whether the patient can provide verbal consent. For instance, if the patient suffers from confusion or altered mental state, language barrier, unconsciousness, intubation, or intoxication, third party consent or two-doctor consent should be organized. At times, if the examination is critical, consenting may be overridden by the

ED consultation. In this case, documentation of the event should be performed and in the patient notes, for future reference.

7 Protocols

Uptake of WBCT has increased widely particularly across developed nations; however, there exists a lack of consensus and standardization of protocols, and indications which warrant these protocols. Pregnant patients and paediatrics are the exception, where non-ionizing modalities are preferred in nearly every case. Ultimately, a pan-scan protocol is justified when it is deemed clinically necessary to scan the body in a single episode, to improve the ability to accurately report the images in trauma centres and reduce the need for repeat scanning. Generally, findings from physical examination in the ED that suggest injury to multiple areas or systems in a hemodynamically stable patient generally warrant a WBCT scan. These findings stem from three general criteria including mechanism of injury, type of injury and physiologic status:

Mechanism of Injury may include, but are\ not limited to, the following events:

- Vehicle collision.
- Explosion.
- Crush injury.
- Fall from a significant height.

Physiologic Status may differ by institution, but common quantitative measurements include:

- Glasgow Coma Scale <10.
- Systolic BP <80 mmHg.
- RR <10 or >29.
- O_2 sat. <90%.

Types of Injuries may include, but are not limited to, the following presentations:

- Flail or open chest.
- Unstable pelvic fracture.
- Fractures >1 long bone.
- Proximal amputation.

(Treskes et al. 2016)

A typical WBCT protocol may consist of both non-contrast and contrast-enhanced scans including any of the following, but not limited to:

- Non-contrast CT https://www.radiopaedia.org/articles/ct-brain?lang=us head.
- Non-contrast CT cervical spine.
- CT thorax and upper abdomen (in arterial or venous phase).
- CT abdomen/pelvis in portal venous phase.

If the following injuries are diagnosed in real time, the following phases may be added:

- CT Carotid/COW for neck injuries https://www.radiopaedia.org/articles/missing?article%5Btitle%5D=ct-angiogram-neck&lang=ushttps://radiopaedia.org/articles/blunt-cerebrovascular-injury?lang=us
- Delayed phase of the abdomen/pelvis: useful to assess for contrast pooling/contrast extravasation indicative of active bleeding.
- Excretory phase of the kidneys or CT cystogram useful in patients with traumatic kidney or bladder https://radiopaedia.org/articles/renal-trauma-1?lang=usinjuries https://radiopaedia.org/articles/urinoma?lang=ushttps://radiopaedia.org/articles/renal-trauma-1?lang=us

Furthermore, variations to protocols may be added depending on radiologist and/or ED physician preferences. These additions may entail:

- Multiplanar reconstructions of the spine.
- Additional non-contrast CT of the upper abdomen.
- CT angiogram of the lower limbs in the setting of suspected major haemorrhage and/or pelvic/lower limb fractures.
- Triphasic injection single pass CT of the chest, abdomen and pelvis.

Considering these points, two specific examples of a suitable protocol with contrast timings and reconstruction techniques are detailed below:

7.1 Patient Preparation

- No fasting.
- No water oral filling.
- Supine.
- OM baseline parallel to scan plane if possible.

7.2 Dual Intravenous Contrast Bolus

- *Non-Contrast Head* (from top of vertex to base of skull) and *Non-Contrast Cervical Spine* (from EAM to T2) performed first (Fig. 1).
- Raise arms above head.

Scan Range: Top of Acromions to Lesser Trochanters (Fig. 2)

Contrast:

- A total of 140 mls Omnipaque 350 contrast and 100 ml of normal saline @ 3-4 ml/s is administered.
  - 70 ml contrast @ 3–4 ml/s followed by 50 ml normal saline @ 3 ml/s. Wait 50 s from start of contrast injection.
  - 70 ml contrast @ 3–4 ml/s followed by 50 ml normal saline @ 3 ml/s.
  - 15 s delay (65 s from start of first contrast injection) then bolus tracking ROI during second contrast bolus on aortic arch and trigger @150HU.

7.3 Single Intravenous Contrast Phase with Two Scan Ranges

- *Non-Contrast Head* (from top of vertex to base of skull) and *Non-Contrast Cervical Spine* (from EAM to T2) performed first (Fig. 1).
- Raise arms above head.

Scan Range: Top of Acromions to Lesser Trochanters (Fig. 2).

A CT angiogram from top of the acromions to the pubic symphysis and a portal venous abdomen and pelvis is obtained.

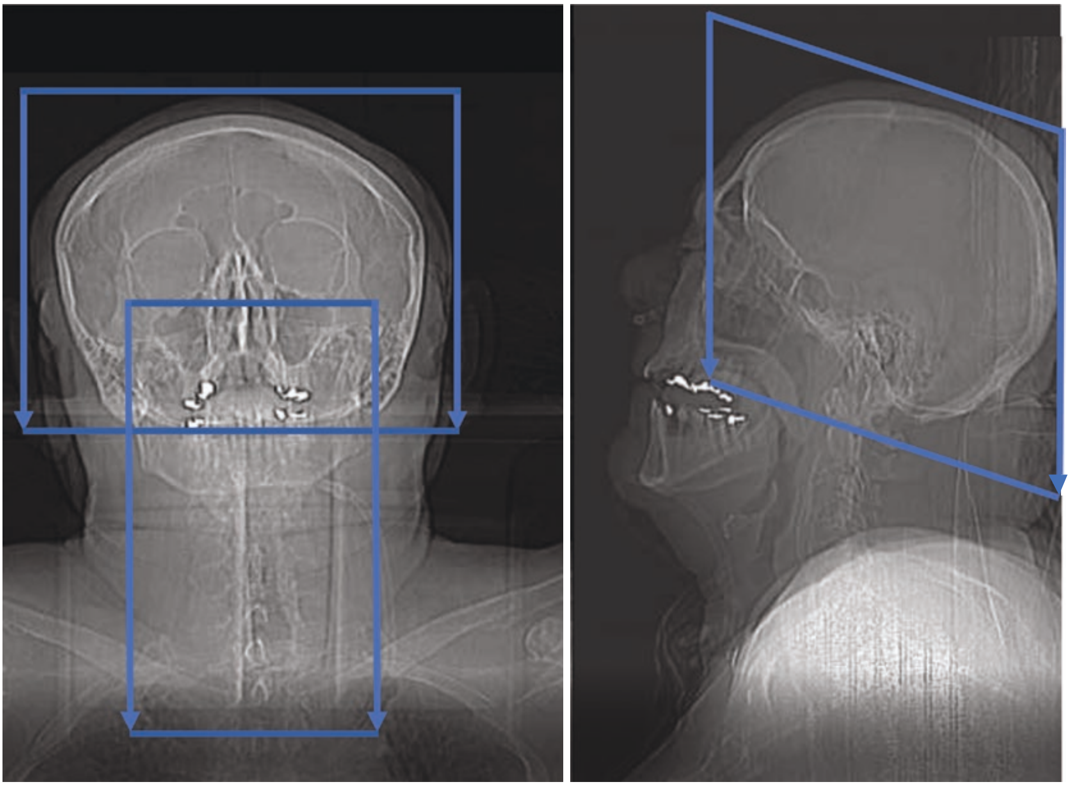

Fig. 1 AP & lateral topogram of head

Contrast:

- 70–100mls contrast @ 3–4 ml/s followed by 50 ml normal saline @ 3 ml/s.
- Post-contrast (arterial phase) chest, abdomen and pelvis bolus tracking ROI after contrast bolus on aortic arch and trigger @100HU.
- Post-contrast (portal venous phase) abdomen and pelvis.

7.4 Image Reconstruction

(Table 1):

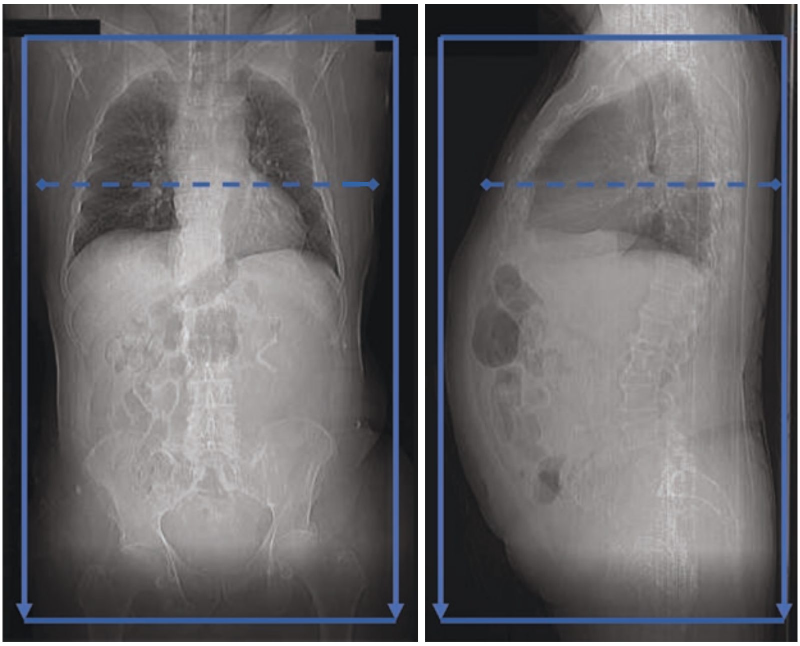

Fig. 2 AP and lateral topogram of chest, abdomen & pelvis with monitoring slice at the level of the pulmonary trunk. Images courtesy of SC

Table 1 Image reconstruction parameters for head, c-spine, chest and chest/abdomen/pelvis (Hassam 2020)

Head		**C-Spine**	
1/1 mm soft tissue	**Axial**	2/2 mm soft tissue	**Axial**
1/0.8 mm bone	**Axial**	2/2 mm soft tissue	**Sagittal**
3/3 mm soft tissue	**Axial**	2/2 mm soft tissue	**Coronal**
3/3 mm soft tissue	**Coronal**	2/2 mm bone	**Axial**
3/3 mm soft tissue	**Sagittal**	2/2 mm bone	**Coronal**
		2/2 mm bone	**Sagittal**
Chest		**Chest/abdomen/pelvis**	
1/0.8 mm lung	**Axial**	3/2 mm soft tissue	**Axial**
8/8 mm lung	**Axial**	8/8 mm soft tissue	**Axial**
3/3 mm lung	**Coronal**	1/0.8 mm bone	**Axial**
		3/3 mm soft tissue	**Coronal**
		3/3 mm soft tissue	**Sagittal**

8 Conclusion

It can be argued that given the superior diagnostic capability of CT, the undeniable fact that WBCT delivers greater radiation dose actually holds limited clinical applicability; rather, it is the degree by which WBCT produces greater dose that is most relevant. Considering the vast benefits of WBCT, ED physicians are faced with a question not uncommon in many aspects of radiology in emergency medicine:

> *How much inferior can traditional diagnostic protocols afford to be in terms of diagnostic accuracy and imaging time, until its benefit of dose-minimization becomes no longer relevant? Or, how much more dose can WBCT afford to produce, until its benefits over conventional protocols become no longer justified?*

Though a solution to this issue can be informed by statistical evaluation of outcomes such as sensitivity, specificity, radiation dose, cost and other patient-related factors, a significant role will always be played by clinical expertise, and professional subjectivity, in determining the most necessary diagnostic pathway for trauma patients. Thus, it is challenging for researchers to devise a threshold for outcomes such as mortality and ED times by which it can be confidently stated that lower or nil-radiation dose modalities become less clinically relevant. Nevertheless, it is estimated that the risk of death from intermediate level trauma is six times higher than the risk of a cancer death from a CT-related radiation exposure (Laack et al. 2011). With technological advancement and exploration of low-dose scanning, this risk is expected to decrease. Currently, it is sensible to prefer WBCT in seriously injured multi-trauma patients but we need further studies defining seriously injured patients and strong rule-out criteria for decision of WBCT.

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Part III

CT Guided Interventions

Indications, Technique and Pitfalls

Edel Doyle and Prasanna J. Ratnakanthan

Abstract

In addition to serving as a diagnostic imaging modality, the use of Computed Tomography (CT) to guide interventional procedures has increased dramatically in the past decade. This is linked to more sophisticated technology available on CT scanners, including interventional options, allowing for 'live' 3-dimensional data to guide the interventionalist to perform the procedure more safely. Interventional CT includes a wide range of procedures such as musculoskeletal joint injections, nerve root corticosteroid injections, aspirations, biopsies, drainages, radiofrequency ablations and transarterial chemoembolisations. The ALARA principle requires consideration of the benefits and risks associated with the use of ionising radiation when performing such interventional procedures. When deciding on the most appropriate modality to guide an intervention, radiation dose and potential complications are two major concerns to be considered. CT fluoroscopy may deliver higher radiation dose than conventional fluoroscopy, but the value of the 3-dimensional data provided by CT to minimise the associated risks or complications to the patient will usually outweigh the radiation-related risks. Radiographers are an integral part of the multidisciplinary team (MDT) when interventional CT procedures are being performed. Therefore, it is vital to the success of the MDT that radiographers understand the aim of the procedure and the associated risks so that they can provide optimal imaging in a timely manner whilst minimising the radiation dose to both the patient and the members of the MDT who may have to remain in the CT scan room during exposure.

Keywords

Intervention · CT-guided · Injection · Biopsy · Fluoroscopy

1 Indications

Computed Tomography (CT) uses ionising radiation (X-rays) to produce images from 360° which assists the interventional radiologist to accurately position a needle to deliver medication or biopsy a lesion. In most cases, the radiation dose in a CT-guided interventional case will often be lower than conventional fluoroscopy, as less imaging may be performed. The procedure may be quicker than under conventional 2D fluoroscopy-guidance, as 3D imaging is provided when CT fluoroscopy is utilised.

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Procedures include spinal injections such as epidurals, facet joint or nerve root exits, and shoulder hydrodilatation, arthroscopies and biopsies may be performed with CT-guidance. The indications for commonly performed CT-guided interventional procedures are outlined in Table 1.

1.1 Technique

Depending on the type of interventional procedure being performed, there are three different techniques that the radiologist may choose to use to guide them:

Table 1 CT-guided interventional procedures

Procedure	Indication(s) and brief outline
Arthrogram (pre-MRI)	Used to introduce contrast into the joint capsule (i.e. arthrogram) prior to MRI scan with intra-articular contrast. The patient should be screened by the MRI staff prior to being consented by the radiologist. An MR-compatible wheelchair should be brought to CT to transfer the patient from CT to MRI. The gadolinium contrast is introduced into the joint capsule under CT-guidance following the intra-articular administration of iodinated contrast.
Biopsy	Radiological imaging is used to guide the insertion of the needle of the biopsy gun into the target lesion so a sample can be taken and sent to pathology for analysis. CT is the preferred modality of choice when involuntary movement is likely (e.g. respiration) or when vital anatomy is located close by.
Drainage	Radiological imaging is used to guide the insertion of a drain into a collection of fluid from an abscess or cavity. Using CT, the drainage catheter is advanced within the fluid collection site, where it is secured, and a drainage bag attached to the catheter. Depending on the volume of fluid, the drainage catheter can be left in situ for a number of days before being removed.
Epidural injection	Used to treat central disc protrusion or spinal canal stenosis. The steroid and local anaesthetic are injected into the (epidural) space between the dura and the spinal cord.
Facet joint injection / medial branch block	Used to treat localised neck or back pain often caused by arthritis, injury or mechanical stress. The steroid is injected into the capsule at the facet (zygapophyseal) joint in the cervical or lumbosacral spine. The aim is to reduce inflammation and provide long lasting pain relief from 3–6 months. Medial branch nerves are small nerves that exit through the facet joints and are responsible for transmitting pain signals from these joints. A medial branch block temporarily interrupts the pain signal from a specific facet joint. The anaesthetic is injected proximal to the medial nerves related to a specific facet joint. Typically several levels of the spine are injected in one procedure.
Hip injection	Used to treat osteoarthritis and labral tear.
Hydrodilatation of the shoulder	Used to treat osteoarthritis and adhesive capsulitis (i.e. ‘frozen shoulder’). The capsule of the shoulder joint is extended (or ruptured) using air by the radiologist to relieve the symptoms of a ‘frozen shoulder’. The aim is to stretch the joint capsule, thereby improving function.
Knee injection	Used to treat osteoarthritis.
Nerve root (perineural)/ foraminal injection	Used to treat radiculopathy due to disc protrusion or foraminal stenosis. The steroid and/or anaesthetic are injected into fat around the nerve where it exits through the spinal foramen. A nerve root injection can assist in diagnosing the vertebral level where the impingement or compression has occurred as it may not be visualised on the MRI scan, and may also provide some pain relief.
Radiofrequency ablation (RFA)	Used to deliver targeted heat to a specific tumour or nerve. Most commonly used to treat metastatic lesions in the liver or damaged nerves. For hepatic RFA, CT scans will include the acquisition of triphasic liver scans 2–3 times during the interventional procedure to see if the tumour is still enhancing. The patient may be under general anaesthetic so liaison with a team external to radiology will be required.
Transarterial chemoembolisation (TACE)	Used to administer chemoembolisation to a vascularised tumour in the liver. Will often involve coordination with the team in the angiography suite.

1. Injection/Biopsy mode = intermittent fluoroscopy, e.g. iSequence (Siemens), ONE Shot (Canon), SmartView (GE).
2. Repeat Scan Range.
3. CT fluoro = intermittent fluoroscopy, e.g. CARE Vision (Siemens), Continuous SURE Fluoro (Canon) and SmartStep (GE).

The complexity of the case should determine which technique the radiologist will use and they may have to change during the case.

1.2 Patient Preparation

The patient may be required to fast if having sedation and the radiology nurse will usually liaise with the patient in advance if this is the case. If a general anaesthetic is involved, the anaesthetics team will liaise with the patient regarding preparation and fasting times. Depending on the procedure, recent blood test results may be required, particularly for patients who take anticoagulants. Most departments will have a checklist that the radiology nurse will complete with the patient when booking the CT-guided procedure. The results of any blood tests and previous imaging should always be checked prior to the interventional procedure as part of a 'Time Out' protocol.

1.3 Consent

The radiologist who will perform the interventional procedure is responsible for explaining to the patient what the procedure will involve and what the likely risks are. This discussion will include the potential radiation risks and those associated with the contrast agent which may be administered intrathecally, intra-articularly or intravenously. The patient should also be informed of the benefits and risks of the interventional procedure planned, as well as any alternative options available to them. Having explained the procedure thoroughly and answered any questions, the radiologist should ask the patient to sign the Consent form which is later scanned into the patient's file on the Radiology Information System.

CT radiographers must be familiar with the side effects of both contrast agents used, as well as the medications administered so that they can identify an adverse reaction and alert the radiologist immediately. Particularly when the patient is sedated, the signs and symptoms may not be noticed by those concentrating on performing the procedure so the CT radiographers should be observing the patient at all times (Royal Australian and New Zealand College of Radiologists 2018b).

In order to be valid, consent must be provided voluntarily by the patient, having been given sufficient information to make a decision and the patient must be competent to make the decision (The Royal Australian and New Zealand College of Radiologists 2019). Even if they have signed this form, the patient can still decline to proceed at any point during the procedure and their decision must be respected—they should not be pressured to proceed. For this reason, it is advised that the patient is 'consented' outside the CT scan room so they have time to 'consider the information given' prior to the interventional procedure starting.

Where available, 'Patient Information' leaflets for the procedure should be provided to the patient to read in advance and sign on the day. If they have any queries, the radiologist can address these prior to commencing the interventional procedure. The Royal Australian and NEw Zealand College of Radiologists' 'Inside Radiology' website (2018a) is an excellent resource for both patients and healthcare professionals to review to further their understanding of interventional procedures: https://www.insideradiology.com.au/interventional-radiology.

1.4 Positioning the Patient

Positioning of patients is the responsibility of the CT radiographer but may involve guidance from the radiologist, depending on their individual preferences. For the common CT interventional procedures, the preferences for each radiologist should be recorded locally to ensure that the procedure is as time-efficient as possible for all involved. For

Fig. 1 Example of set-up for interventional CT procedure. Image Courtesy of Canon Medical and Dr. Smit, Radboudumc, the Netherlands (Canon Medical Systems ANZ, 2021)

Fig. 2 Webb medical fast find grid. Image courtesy of Webb Medical (2020)

more complicated procedures, e.g. biopsy, this will vary depending on the location of the lesion.

The position of the patient in the CT scanner is directly linked to the radiation dose that they receive so accurate positioning to minimise the radiation dose to the patient is desired (i.e. the ALARA Principle—As Low As Reasonably Achievable). With multislice CT scanners, the body part of interest must be positioned in the isocentre (i.e. the direct centre of the gantry) in order to optimise image quality. Sometimes this is not possible, as adequate space to work must be available for the interventional equipment within the gantry but the radiographer must be aware of the impact on subsequent radiation dose and therefore, image quality. An example of the set-up for a CT-guided interventional procedure is shown in Fig. 1.

The adhesive single-use interventional grid should be placed on the patient's skin over the region of interest prior to the topogram (Fig. 2).

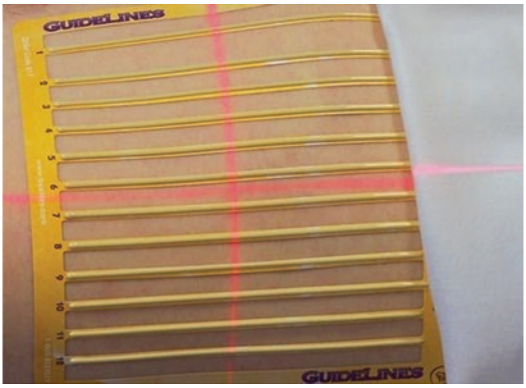


Fig. 3 Beekley Medical Guidelines with laser cross-hairs. Image courtesy of Beekley Medical (2020)

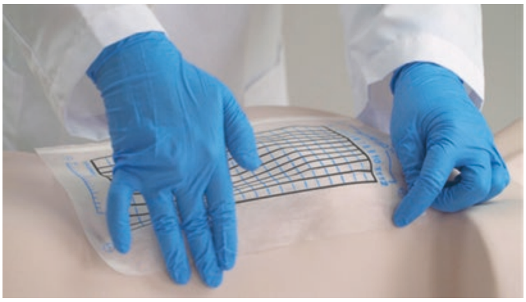


Fig. 4 Webb medical fast find grid. Image courtesy of Webb Medical (2020)

It is important that the lead lines within the grid are perpendicular to the z-axis of the scan field to ensure they are visible on the pre-planning scan. There are two main types of grids available as shown below in Figs. 3 and 4.

1.5 Pre-Planning CT Scan

The patient will already have had a diagnostic CT or an MRI scan prior to the interventional procedure. Therefore, the pre-planning scan can be limited to a small range, e.g. ½ vertebral body above the inter-vertebral disc space to ½ vertebral body below (Fig. 5).

Allow the images to reconstruct prior to asking the radiologist to review—if the radiologist measures/marks the spot on the 'Real Time' images instead of the reconstructed images, the line will disappear. The radiologist uses the grid on these images to decide where s/he will insert the needle (Fig. 6).

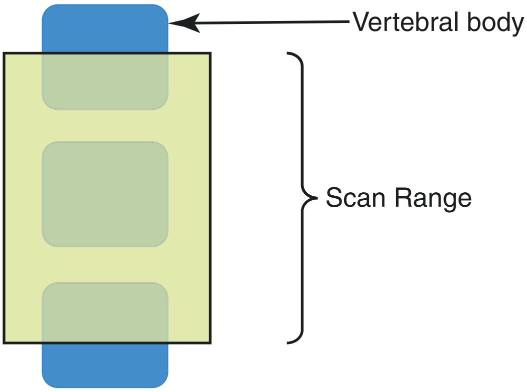


Fig. 5 Scan range for pre-planning scan

Fig. 6 Beekley Medical Guidelines on the skin allowing radiologist to plan entry site and direction of needle insertion. Image courtesy of Beekley Medical (2020)

Once an appropriate needle insertion slice has been planned, the CT radiographer will then mark that spot on the patient's skin using a surgical marker (or equivalent). It is important that the radiographer checks that the needle entry site has been clearly marked on the patient's skin prior to removing the grid, as this can be erased by antiseptic solution whilst creating a sterile environment for the procedure (Figs. 7 and 8).

1.6 Procedure

All CT-guided interventional procedures are performed in a sterile environment. When the radiologist has donned sterile gloves, they will open the sterile pack on a trolley. They will clean the patient's skin at the marked region of interest. A sterile drape may be used to cover the patient to preserve the sterile field and minimise the risk of

Fig. 7 Marking the spot on the patient's skin using the laser light for guidance with the Webb Medical Fast Find Grid. Image courtesy of Webb Medical (2020)

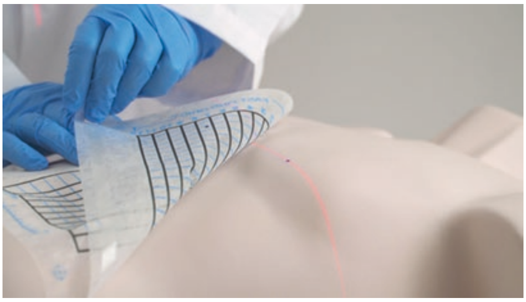


Fig. 8 Confirming the spot is visible on the patient's skin whilst gently removing the Webb Medical Fast Find Grid. Image courtesy of Webb Medical (2020)

infection. Local anaesthetic may be administered subcutaneously. If a nurse is not available to assist the radiologist, it is vital that the CT radiographer double-checks all vials of medication and expiry dates with the radiologist prior to administration. Batch numbers and expiry dates should be recorded in the patient's file on RIS in case of an adverse reaction or re-call by the manufacturer.

1.7 Acquisition Option 1: Injection/Biopsy Mode (I.E. Intermittent CT Fluoro)

The radiologist will use the overhead TV screen (i.e. monitor) in the CT scan room to gauge the depth of penetration of the needle. This should be positioned on the opposite side to where s/he will be working from. The CT table can be moved out for the radiologist remotely by the CT radiographer to allow for repositioning by the radiologist. The CT radiographer should ensure that the table is returned to the needle entry position before any further acquisitions are undertaken. The central image should be centred on the needle tip with an image shown at levels above and below (Fig. 9).

1.8 Acquisition Option 2: Scanning a Range

This option is often used to increase the scan range or display field of view (DFOV) so the radiologist can see the extravasation of intra-articular contrast, it is easiest to close the INJECTION/BIOPSY protocol & open up a RANGE (same FOV, X- & Y co-ordinates). The shortest scan range possible should be acquired to see where the contrast is. Depending on the CT scanner, it may be possible to change between scanning a range and the INJECTION/BIOPSY protocol if needed.

1.9 Acquisition Option 3: CT Fluoroscopy

This is a continuous CT fluoroscopy technique which allows the radiologist to screen 'live'. The hand controls should be attached to the side of the CT table that the radiologist will work from and the foot pedal moved into position. The TV monitor should be moved into position on the opposite side of the CT table so that it is easily seen by the radiologist whilst performing the procedure (Fig. 10).

There is usually a Soft and a Bone CT Fluoro protocol to choose from:

- Use 'Soft' for Nerve Root.
- Use 'Bone' for Facets and Epidurals.

Remember, the windows can be changed to Bone on the Soft protocol but not vice versa.

Different vendors offer a variety of options and may display 3, 5 or 7 images with:

- 3 images of the same size, centred on the needle
- 1 large image (centre) and 2 smaller images (head & foot).

Figure 11 shows three images of the same size, along with a reference line (pink) on the topogram to localise the scan position anatomically.

1.10 Summary of Technique for CT Radiographer

As the procedure is quite similar from the radiographer's perspective, only patient positioning will be discussed for musculoskeletal (MSK) injections which includes all spinal, shoulder, hip and knee injections. An example will also be provided for a lung biopsy and a biopsy of the abdomen.

For all patients, patient preparation is the same:

- Confirm patient ID.
- Confirm pregnancy status of female patients of child-bearing age.
- Radiologist completes consent form.
- Change patient into gown.
- Remove radiopaque artefacts from the area of interest.

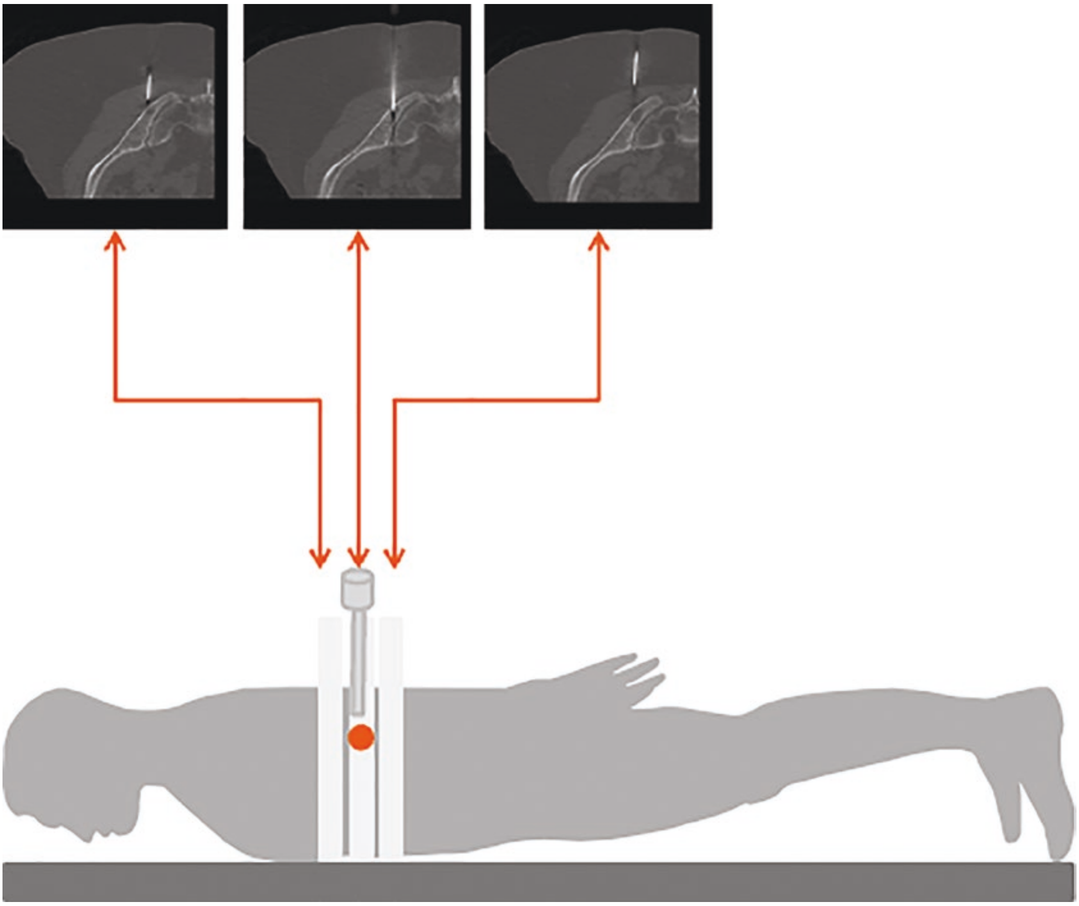


Fig. 9 Example of iSequence from Siemens demonstrating three slices, centred upon the needle tip. Images Courtesy of Siemens Healthineers (2021)

Fig. 10 Room set-up for CT-guided interventional procedure. Personal photo

If any breathing instructions are required, these should be practiced with the patient in advance, particularly if they are sedated. It must be appreciated that patient compliance may be affected by sedation. Where the radiographer remains at the console outside the CT room, the microphone should be turned on to communicate with the radiologist during the procedure.

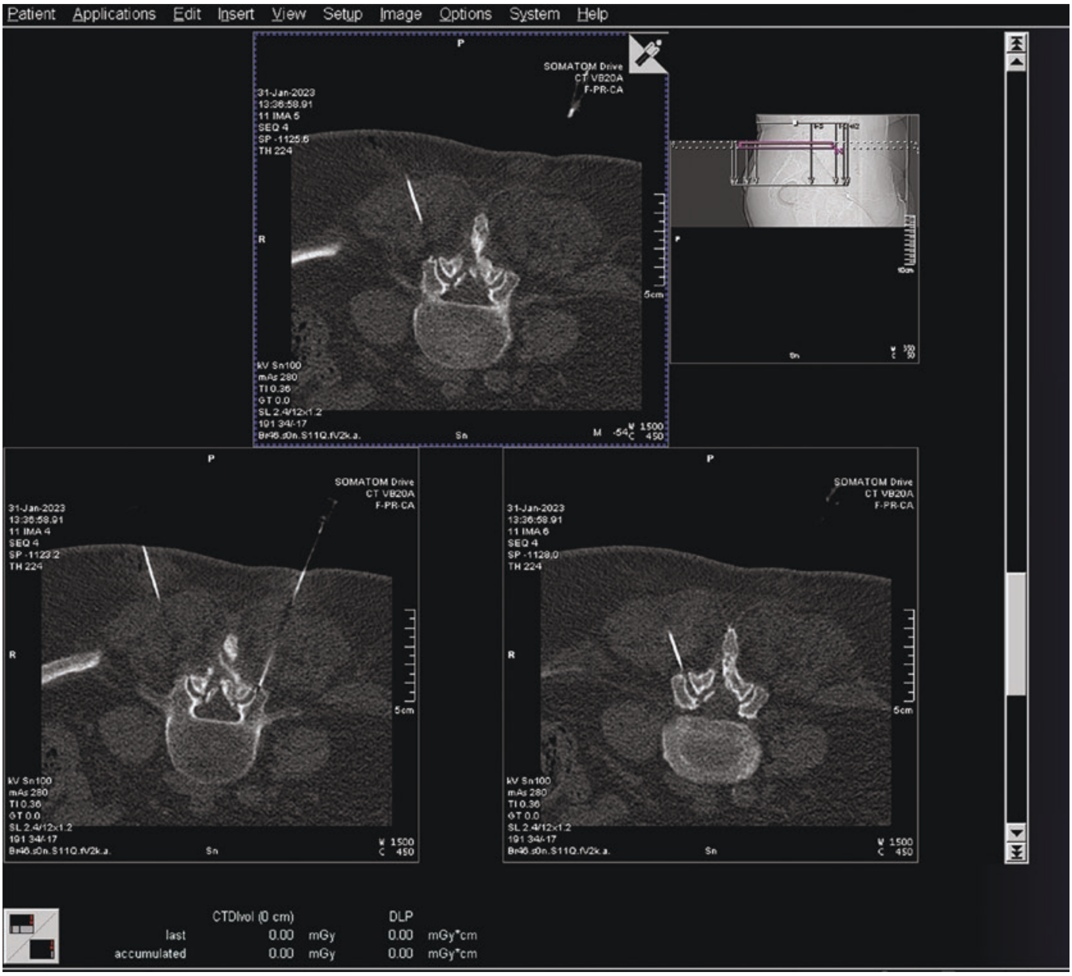


Fig. 11 Example of three images for CT-guided interventional procedure. Images Courtesy of Siemens Healthineers (2021)

1.11 Lumbar Spine Injections

When performing a facet joint injection or medial branch block, there is no clinically significant difference in terms of effectiveness based upon the injection being administered into the facet joint or the pericapsular soft tissues. However, if treating a neural compression, then the injection must be administered intra-articularly (Watson and Jones 2018).

Nerve root injections are generally administered to more complex patients. It is very important that recent MRI scans are reviewed to confirm the correct side and vertebral level(s) to be injected. The objective is to locate the needle tip outside the nerve root sheath so when the injection is administered, it passes between the prolapsed disc and the compressed nerve. Correct location of the needle tip (i.e. inferior and lateral to the ipsilateral pedicle) is confirmed with a test injection of iodinated contrast agent which should outline the extraforaminal nerve roots. Care must be taken not to inject accidentally into a spinal artery, and the risk of this occurring should be discussed with the patient as part of the consent process. In rare cases, it can cause paraplegia. Alleviation of symptoms can be slow and may take 2–3 months (Watson and Jones 2018).

Table 2 summarises the procedure for a CT radiographer when providing CT-guidance for a lumbar spine injection. The technique is similar for all types of injections.

Table 2 Lumbar spine injection procedure

<table>
<tr><td>Patient position</td><td colspan="3">• Patient lies head first prone on scan table
• Position laser lights (topogram/scanogram):
– X-axis: In the midline, at level of diaphragm
– Z-axis: Midway between anterior & posterior skin margins
• Apply radiopaque CT interventional grid over area of interest (with grid lines parallel to Z-axis)
• Explain the importance of staying still to the patient</td></tr>
<tr><td>Scan range topo</td><td colspan="3">Topo direction: Cranio-caudal
From: T11
To: S3</td></tr>
<tr><td>Scan range pre-plan</td><td colspan="3">Pre-planning scan to include:
½ vertebral body above & below inter-vertebral level, as guided by radiologist</td></tr>
<tr><td>Recons pre-plan</td><td>Creating:</td><td>Series description:</td><td>To include:</td></tr>
<tr><td></td><td>Thick –axial softs</td><td>L-Sp_Pre-Plan 2 mm [spine]</td><td>½ vertebral body above & below inter-vertebral inj level</td></tr>
<tr><td></td><td>Thick –axial bones</td><td>L-Sp_Pre-Plan 2 mm [bone]</td><td>½ vertebral body above & below inter-vertebral inj level</td></tr>
<tr><td>Procedure</td><td colspan="3">• If the radiologist is screening from inside the CT scan room using CT Fluoro:
– Attach the joystick to the side of the CT table & position the foot pedal on the side they will be working from. Position the monitor on the opposite side.
– Switch on HAND CARE if available
– Turn on the speaker on CT control panel so you can hear the radiologist!
• Adjust the DFOV to include the L-spine, as well as the skin markers. Note the FOV, X & Y co-ordinates.
• Recon both the soft & bone pre-planning scans, then call the radiologist.
• Radiologist reviews the pre-planning scan & selects the point of entry by measuring angle/distance from grid on the skin surface.
• Document slice position [SP].
• Move the CT table to that position. Go into the CT scan room, turn on laser light and mark the spot using a permanent marker. Then move the patient out of the gantry ready for the radiologist to start.</td></tr>
<tr><td>Scan range injection</td><td colspan="3">• This mode usually acquires three slices of 2-3 mm thick—Centre, head & feet.
• On the pre-planning images, select the slice of interest where the radiologist marked the angle of entry. Then move the table to that position. This table position will be the centre image. EXPOSE.
• Select head, centre or foot image where tip of needle is demonstrated & move the table to that position. EXPOSE.</td></tr>
<tr><td>Recon’s injection</td><td>Creating:</td><td>Series description:</td><td>To include:</td></tr>
<tr><td></td><td>Thick –axial soft</td><td>L-spine_Inj 2–3 mm [Spine]</td><td>Needle tip</td></tr>
<tr><td>Scan range Range1</td><td colspan="3">If the needle is being inserted at an angle, the radiologist may choose to angle/tilt the gantry OR to ‘Repeat range’ from pre-planning scan:
• When reconstructing, enter the FOV, X & Y co-ordinates from the reconstructed pre-planning images
• Set a short scan range & REPEAT as required</td></tr>
<tr><td>Recon’s Range1</td><td>Creating:</td><td>Series description:</td><td>To include:</td></tr>
<tr><td></td><td>Thick –axial soft</td><td>LSpInj_Range1 2.0 [spine]</td><td>Needle tip</td></tr>
<tr><td></td><td>Thick –axial bone</td><td>LSpInj_Range1 2.0 [bone]</td><td>Needle tip</td></tr>
<tr><td>Scan range CT Fluoro</td><td colspan="3">• Radiologist may choose to use this mode if it is a challenging patient
• This mode acquires three slices of 5–7 mm thick—centre, head & feet.
• When reconstructing, enter the FOV, X & Y co-ordinates from the reconstructed pre-planning images
• The radiologist will position the table using the joystick and screen using the foot pedal.
• Different radiologists like different viewing—1 big box, 2 small & 1 big, three equal size…check radiologist’s preferences.</td></tr>
</table>

(continued)

Table 2 (continued)

Recon's CT Fluoro	Creating:	Series description:	To include:
	Thick –axial soft	CTF_Soft 2-3 mm [spine]	Needle tip
	Thick –axial soft	CTF_bone 2-3 mm [Bone]	Needle tip
Post-processing	• Select image with needle tip where injection was given. Note series & image number. • Add reference line & SAVE • There should be two images—topo/scano (with reference line) & image with tip of biopsy needle • Zoom up the topo if necessary • SAVE AS…"Inj site" • Document radiation dose (CTDIvol & DLP), patient's height and weight. • CLOSE exam.		
Archive to PACS	• Topo/Scano • Pre-planning scans • Injection site • Dose report		
Medicare billing	57341 CT interventional 104 consultation And… • 39013 facet • 18232 epidural • 18276 nerve root block		

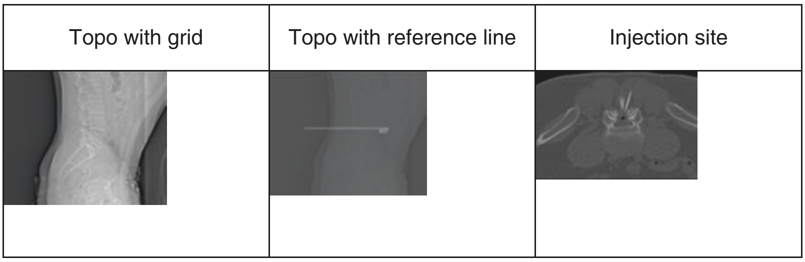

Topo with grid
Topo with reference line
Injection site

Fig. 12 L4/5 epidural injection. Example of images sent to PACS. Images reproduced with permission

Figure 12 shows the final images that are commonly sent to PACS for an epidural injection into the lumbar spine.

1.12 Cervical Spine Injections

When performing nerve root injections of the cervical spine, extreme care must be taken to ensure that the needle tip is located correctly. The risk of accidental intravascular injection, particularly to the vertebral artery, is higher than in the lumbar spine. When inserting the needle, the radiologist should ensure that it passes posterior to the carotid and jugular vessels, aiming towards the outer bony rim of the posterior aspect of the foramen in order to avoid both the vertebral blood vessels and the nerve root (Watson and Jones 2018).

1.13 Shoulder Hydrodilatation ± Injection ± Arthrogram

If the needle is correctly located within the shoulder joint capsule, a test injection of contrast will disperse from the needle tip around the joint within the capsule (Fig. 13).

If the needle is not correctly located, the contrast media remains concentrated at the tip of the needle. Iodinated contrast is usually absorbed from the joint and excreted from the body within a few hours. However, if air is injected to dilate

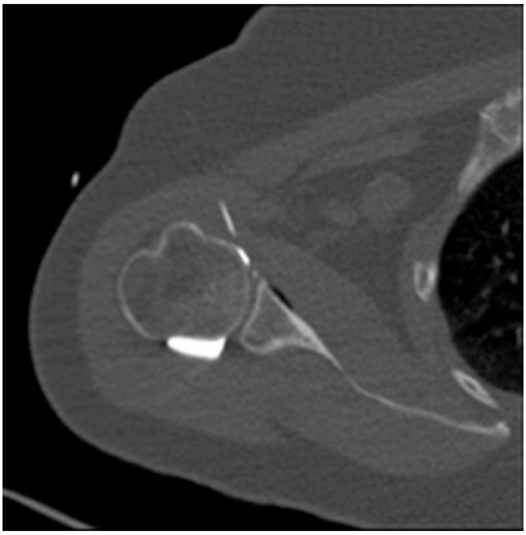


Fig. 13 Patient positioned supine with anterior approach and contrast injected. Image reproduced with permission

Fig. 14 Patient positioned lateral decubitus with posterior approach and air injected. Image reproduced with permission

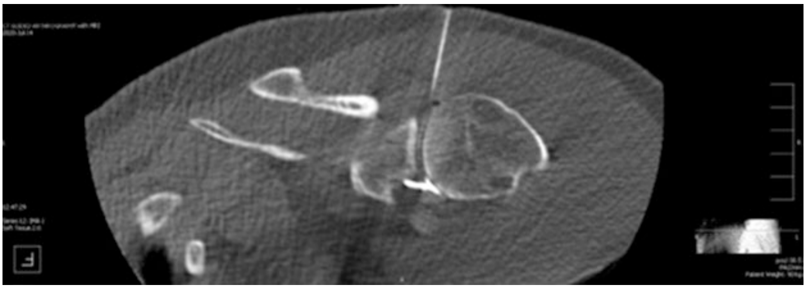


Fig. 15 CT image showing needle entering shoulder joint and contrast media dispersed. Topogram with reference line is present in bottom right corner. Image reproduced with permission

the joint capsule, not only can this be quite painful for the patient at the time, it may also take up to 4 days to be absorbed (Fig. 14).

If the patient is going for an MRI arthrogram immediately following the CT scan, it is important that any air bubbles within the shoulder joint are removed, as they will cause an artefact on the MRI images. Approximately 15 ml of diluted low osmolar contrast agent is injected into the shoulder (Watson and Jones 2018) (Fig. 15).

Patient positioning can vary and may involve anterior, modified anterior or posterior approach to the glenohumeral joint. For the anterior approach, the patient lies supine on the CT table with the affected arm externally rotated. The other arm may be raised above their head if the patient can tolerate it. This approach offers two main advantages:

1. Removes long head of the biceps tendon away from the region of interest and
2. Facilitates a vertical needle entering the glenohumeral joint without damaging the glenoid labrum.

Fig. 16 Patient lateral decubitus positioning for posterior approach. Personal photo

The posterior approach may be favoured by the patient if they don't want to watch. The patient is prone or in the lateral decubitus position with the affected shoulder raised on the CT table with a sponge under the affected shoulder to raise it slightly (Fig. 16).

The affected arm is relaxed (half-way between pronation and supination) so that the posterior capsule is relaxed. This approach requires the needle to go through less soft tissue (Watson and Jones 2018). Table 3 summarises the procedure for a CT radiographer when providing CT-guidance for a shoulder injection using the posterior approach.

Figure 17 shows the final images that are commonly sent to PACS for an injection into the shoulder.

1.14 Hip Injection

When injecting into the hip, a test injection of iodinated contrast may be administered after the radiologist has felt a 'give' as the needle passes through the joint capsule. The contrast should be seen to disperse away from the needle tip, thereby confirming that the needle is correctly located at the level of the femoral neck, immediately below the junction with the femoral head. Table 4 summarises the procedure for a CT radiographer when providing CT-guidance for a hip injection. The technique is similar for all types of musculoskeletal injections.

Table 3 Shoulder injection procedure

Patient position	• Posterior approach—patient lies on scan table with head first • Position laser lights: – *X-axis:* Superior skin border of shoulder – *Z-axis:* Along axis of humeral head • Apply radiopaque CT interventional grid over lateral aspect of shoulder distal to coracoid process (with grid lines parallel to Z-axis)		
Scan range topo	Topo direction: Cranio-caudal From: Skin borders superiorly To: Inferior angle of scapula		
Scan range pre-plan	Pre-planning scan to include: Region of interest, as guided by the radiologist. • Usually AC joint to inferior border of glenoid fossa		
Recons pre-plan	*Creating:*	*Series description:*	*To include:*
	Thick–axial bone	Shoulder bone 2–3 mm [bone]	Skin superiorly to inferior angle of scapula, including skin margins and medial end of clavicle
Recon's injection	*Creating:*	*Series description:*	*To include:*
	Thick–axial soft	Shoulder bone 2–3 mm [bone]	Shoulder joint capsule
Recon's CTF_ Bone	*Creating:*	*Series description:*	*To include:*
	Thick–axial soft	Shoulder bone 5–7 mm [bone]	Needle tip
Medicare billing	57341 CT interventional		

Figure 18 shows the final images that are commonly sent to PACS for an epidural injection into the lumbar spine.

1.15 Knee Injection

In accordance with the ALARA principle, knee injections may be performed under ultrasound guidance with no exposure to ionising radia-

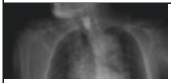
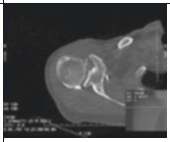
Topo with grid	Topo with reference line	Injection site
		

Fig. 17 Right shoulder injection. Example of images sent to PACS. Image reproduced with permission

Table 4 Hip injection procedure

Indications	To introduce steroid into the hip joint		
Patient position	• Patient lies supine/prone on scan table with feet first • Arms overhead • Position laser lights: – *X-axis:* Iliac crests – *Y-axis:* Mid-sagittal plane – *Z-axis:* Midway between anterior & posterior skin surfaces of pelvis • Apply radiopaque CT interventional grid over antero-lateral aspect of hip at level of ASIS (with grid lines parallel to Z-axis) • Explain the importance of staying still to the patient		
Scan range topo	Insert RIGHT or LEFT into 'comment' field Topo direction: Cranio-caudal From: Iliac crest To: Lesser trochanter		
Scan range pre-plan	Pre-planning scan to include: ASIS to inferior aspect of acetabulum		
Recon's pre-plan	*Creating:*	*Series description:*	*To include:*
	Thick–axial bone	Hip_Pre-Plan 3 mm [bone]	ASIS superiorly to inferior aspect of acetabulum inferiorly, including skin margins laterally
Recon's injection	Thick–axial soft	Hip inj 2–3 mm [bone]	Needle tip
	Thick–axial soft	HipInj_Range1 3 mm [bone]	Hip joint capsule
Medicare billing	57341 CT interventional		

tion or using fluoroscopy where the radiation exposure is expected to be lower than using CT.

1.16 Lung Biopsy

Lung biopsies should only be performed in a hospital environment with a resuscitation team available on-site. The patient should be fasting for sedation. The patient will be positioned according to the location of the lesion in order to provide the shortest access to the lesion from the skin surface, avoiding any major internal anatomical structures. The patient should be sedated and their vital signs monitored throughout the procedure by a nurse. The radiographer should be aware of any leads (or drains) attached to the patient that may be dislodged when the table moves during the procedure, particularly if they are hidden by the sterile drape. The biopsy needle should be advanced upon suspended respiration, having practiced in advance with the patient. There should also be a familiarisation opportunity for the patient to hear the biopsy gun being triggered as it can be an unexpected noise causing the patient to move which is highly undesirable. A common complication of

Fig. 18 Left hip injection. Example of images sent to PACS

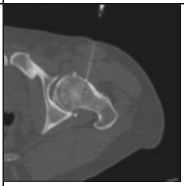
Topo with metallic strip to use as a grid/guide	Topo with reference line	Injection site
		

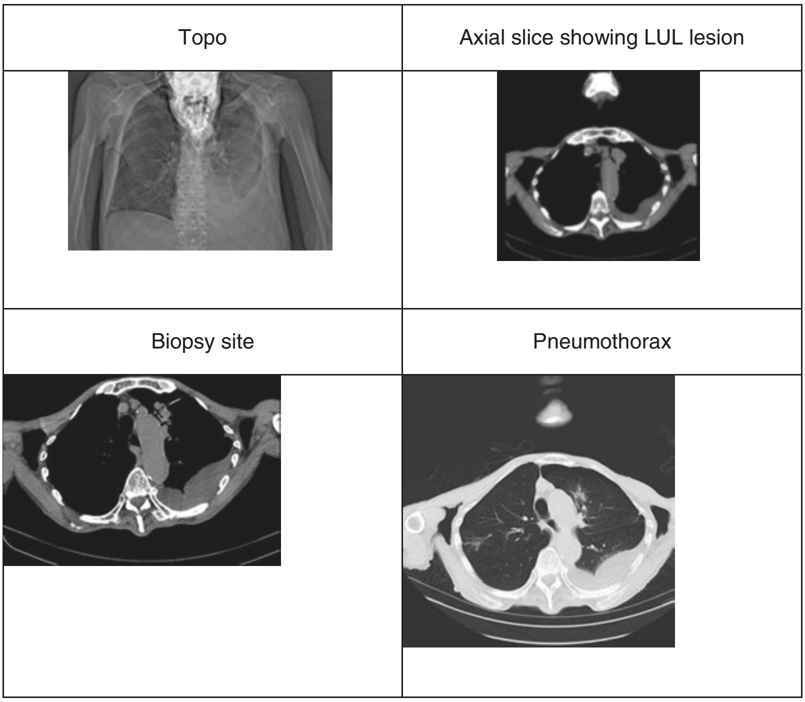
Table 5 Lung biopsy/drainage procedure

Indications	Lesion identified on previous imaging—lung, mediastinum…		
Patient position	• Patient lies supine/prone on scan table with head first • Arms overhead • Position laser lights: – *X-axis:* Apices – *Y-axis:* Mid-sagittal plane if supine/spinous processes if prone – *Z-axis:* Midway between anterior & posterior skin surfaces of chest • Apply radiopaque CT interventional grid over area of interest (with grid lines parallel to Z-axis)		
Scan range topo	Topo direction: Cranio-caudal From: Apices To: Diaphragm (lower posteriorly) OR region of interest, as specified by radiologist		
Scan range chest C-	Pre-planning scan to include: Region of interest ONLY, as guided by radiologist		
Recon's chest C-	*Creating:*	*Series description:*	*To include:*
	Thin–axial softs	Chest C- 0.5–1 mm soft [med]	ROI superiorly to inferiorly, including skin margins laterally
	Thin–axial lungs	Chest C- 0.5–1 mm sharp [lung]	ROI superiorly to inferiorly, including skin margins laterally
	Thick–axial softs	Chest C- 5 mm soft AX	ROI superiorly to inferiorly, including skin margins laterally
	Thick–axial bones	Chest C- 5 mm bone AX	ROI superiorly to inferiorly, including skin margins laterally
	Thick–axial lungs	Chest C- 5 mm lung AX	ROI superiorly to inferiorly, including skin margins laterally
Recon's biopsy	*Creating:*	*Series description:*	*To include:*
	3 thick images	Biopsy 2.4 < body medium smooth +soft> [med]	Tip of needle/biopsy gun on Centre image
Medicare billing	57341 CT interventional 38812 lung biopsy 104 consultation		

a lung biopsy is a pneumothorax which occurs in ~20% of cases. Therefore the patient should be monitored closely after the procedure. The patient may require a non-contrast CT chest immediately following the biopsy to rule out a pneumothorax. They will most likely require a CXR 2–4 h post-procedure. Table 5 summarises the procedure for a CT radiographer when providing CT-guidance for a lung biopsy/drainage and Table 6 for a biopsy/drainage within the abdominal cavity. The technique is similar for all types of biopsies and drainages. Figures 19

Table 6 Abdomen biopsy/drainage procedure

Indications	Lesion identified on previous abdominal imaging—liver, renal, spine…		
Patient position	• Patient lies supine/prone on scan table with head first • Arms overhead • Position laser lights: – X-axis: Nipples – Y-axis: Mid-sagittal plane – Z-axis: Midway between anterior & posterior skin surfaces of abdomen • Apply radiopaque CT interventional grid over area of interest (with grid lines parallel to Z-axis)		
Scan range topo	Topo direction: Cranio-caudal From: Diaphragm To: Symphysis pubis & skin margins laterally		
Scan range Abdo C-	Pre-planning scan to include: Region of interest ONLY, as guided by radiologist		
Recon's Abdo C-	*Creating:*	*Series description:*	*To include:*
	Thin –axial softs	Abdo C- 0.5–1 mm soft [Abdo]	ROI, including skin margins laterally
	Thick–axial softs	Abdo C- 5 mm AX [Abdo]	ROI superiorly to inferiorly, including skin margins laterally
Recon's biopsy	*Creating:*	*Series description:*	*To include:*
	Three thick images	Biopsy 2–3 mm soft [Abdo]	Tip of needle/biopsy gun on Centre image
Medicare billing	• 57341 CT interventional • 30094 aspiration biopsy—this may be a different code, depending on what is being biopsied • 104 consultation		


Topo

Axial slice showing LUL lesion

Biopsy site

Pneumothorax

Fig. 19 Lung biopsy of left upper lobe mass. Examples of images sent to PACS. Images reproduced with permission

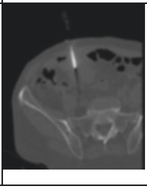
Topo with grid	Pre-Planning (Soft Tissue)	Biopsy site (Bone)
		

Fig. 20 Biopsy abdominal mass. Examples of images sent to PACS. Images reproduced with permission

and 20 show the final images that are commonly sent to PACS for a lung biopsy and an abdominal biopsy.

2 Pitfalls

The biggest risk when performing CT-guided interventional procedures is that the patient may move. The CT radiographer must be familiar with the CT scanner to get the scan centred back on the needle as quickly as possible. It is very helpful to practice breathing instructions with the patient to ensure that they take the same sized breath each time.

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Tips, Tricks, Radiation Dose and Protection

Edel Doyle and Prasanna J. Ratnakanthan

Abstract

Once the patient is set up on the CT table in the most suitable position with the radio-opaque grid placed on their skin, a 'Pre-Planning' scan over the area of interest is acquired. The radiologist uses this scan to assess the anatomy and decide the best access point and direction for the needle. It is very important to try and get the patient as comfortable as possible (this can sometimes be difficult to achieve) to ensure the patient can remain still for the entire duration of the procedure. This is very important for maintaining sterility, and also so the planned entry site and direction of needle are consistent with the initial planning scans, thereby minimising any complications.

Keywords

Low dose · Dose limitation · Radiation protection · Tips and tricks · CT imaging

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1 Tips and Tricks

The radiologist scrubs up, cleans and drapes the patient, and begins the procedure. To track the needle position throughout the procedure, we usually use the 'Injection/Biopsy' protocol which gives the radiologist three images with the central one centred on the needle tip. Occasionally, CT fluoro may be used or a 'low dose' helical range acquired. It does not cover a large scan range, but is adequate for checking needle positions. A longer range may be requested by the radiologist if there is a complication and a larger anatomical area needs to be visualised, but this is usually only required at the end of a lung biopsy to rule-out a pneumothorax.

2 Radiation Dose and Radiation Protection

If CT fluoroscopy is not available on the CT scanner, local protocols will require a short 'range' to be acquired and then repeated. This is not ideal as the radiation dose is significantly higher for the patient. If a department is intending to perform interventional procedures regularly, a CT scanner with the appropriate technology should be procured.

S. Chau, C. Hayre (eds.), *Computed Tomography*, https://doi.org/10.1007/978-981-19-9346-6_9

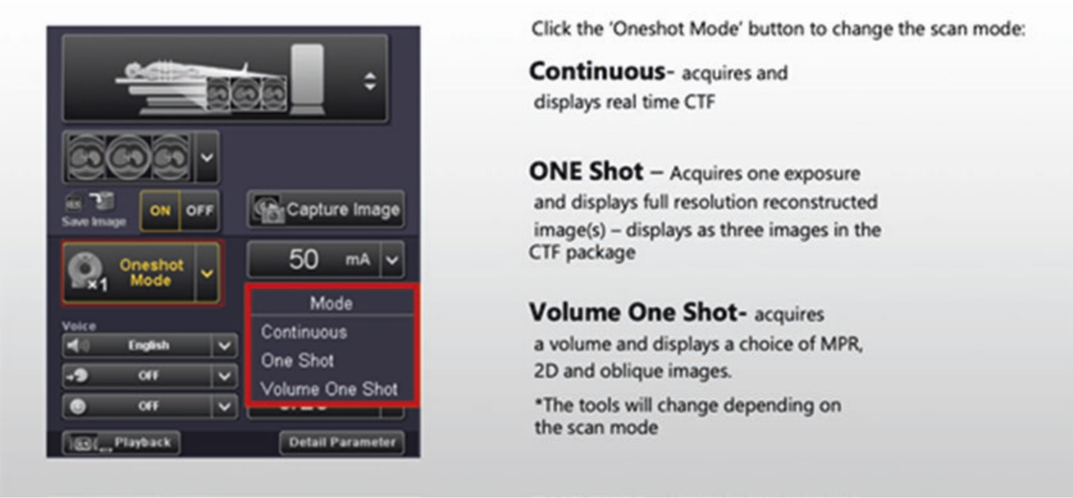
2.1 Clinical Example of Dose Reduction for CT-Guided Lumbar Spine Injections

- CARE Vision is Siemens ‘live’ continuous fluoroscopy screening mode, whereas ‘Repeating the range’ literally involves repeating the Pre-Planning scan (2 mm slices). It presumed that the CT radiographer would reduce the exposure parameters in accordance with the ALARA principle. One way of achieving a lower dose is by reducing kV instead of mA.
- ‘New’ injection = Biopsy mode is an intermittent fluoroscopy mode = 3 images: 1 at needle tip, 1 (2.4 mm) above & 1 (2.4 mm) below.

Figure 1 shows the different options offered by Canon CT scanners.

Radiation dose in CT is measured by CTDIvol (per slice) and DLP (CTDIvol x scan range/length). These are estimations based on scanning a phantom. They are calculations of the radiation dose emitted by the CT scanner but are not equal to the dose received by the patient. In order to calculate local Diagnostic Reference Levels (DRLs), the CTDIvol, DLP, height & weight should be recorded for the interventional protocol that was utilised by the radiologist, i.e. dose from the ‘Pre Planning’ scan should not be included. This data can then be used to calculate a facility DRL (fDRL) and should be reviewed regularly to optimise radiation dose, ensuring that patients receive the lowest radiation dose possible whilst providing adequate image quality that the radiologist can safely perform the CT-guided interventional procedure (Fig. 2). With support from a medical physicist, radiation doses from CT can be compared to fluoroscopy for similar procedures.

Following a dose reduction initiative for interventional CT procedures, an audit in one particular department showed that the ‘Injection/Biopsy’ protocol used the lowest radiation dose. Since introducing this technique in May 2015, the facility (fDRL) for a CT-guided injection of the lumbar spine was reduced by 70% compared to scanning a range and is 90% lower than when using CARE Vision. CT fluoro (CARE Vision) was reserved for more complex cases, and Repeat Range was only used when required to view a longer scan length but this is associated with an increased DLP due to the definition of DLP. This example demonstrates how radiographers can lead a dose reduction strategy in a CT department in a collaborative project with the multidisciplinary team within radiology.



Click the ‘Oneshot Mode’ button to change the scan mode:

Continuous- acquires and displays real time CTF

ONE Shot – Acquires one exposure and displays full resolution reconstructed image(s) – displays as three images in the CTF package

Volume One Shot- acquires a volume and displays a choice of MPR, 2D and oblique images.

*The tools will change depending on the scan mode

Fig. 1 CT fluoroscopy options on a Canon CT scanner. Image Courtesy of Canon Medical (Canon Medical Systems ANZ, 2021)

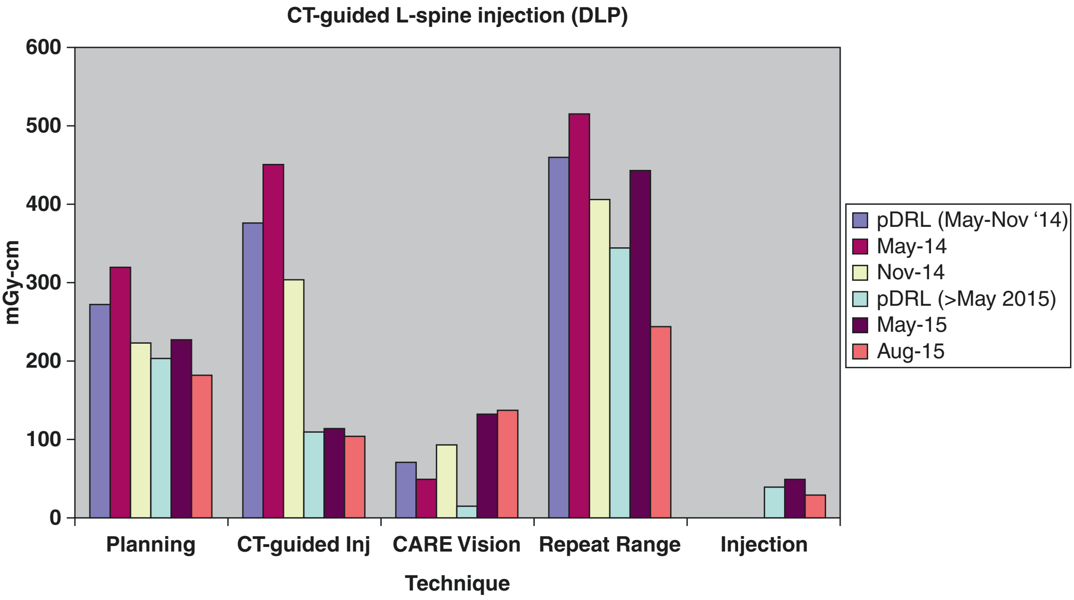


Fig. 2 Chart comparing DLP for departmental lumbar spine injections following a change in protocol. Figure reproduced with permission

2.2 Radiation Protection of Staff

Where possible, staff not required to be in the CT room during exposure should leave. If the radiologist and/or nurse must remain in the CT room during exposure, they must wear appropriate personal protective equipment and should be shielded using mobile lead screens. Use of the inverse square law should be applied. Staff should position themselves where radiation dose is lowest in accordance with the dose map for the local CT scanner (Figs. 3, 4, and 5).

2.3 Methods to Reduce Occupational Radiation Dose

Where available, technological dose reduction options such as Siemens HAND Care or Canon Partial Exposure should be turned on when the radiologist is operating the CT scanner and remaining next to the patient during the procedure. This feature turns off the radiation on the side that the radiologist is located in order to reduce the scatter radiation from the patient in that area (Figs. 6 and 7).

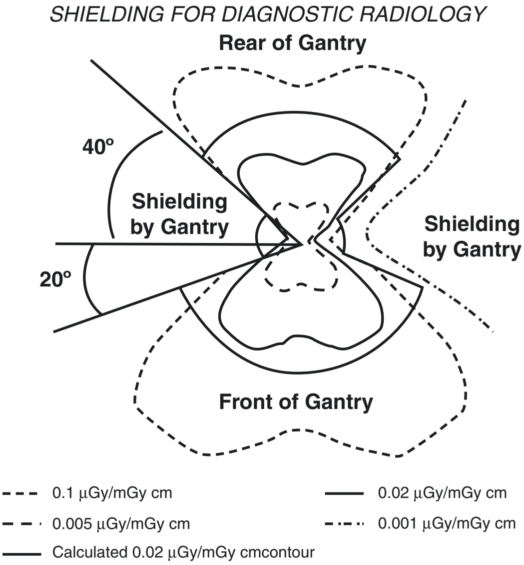


Fig. 3 Isodose map for CT scanner (Martin 2015) showing that the lowest radiation dose will be received when standing beside the gantry

For procedures that will have longer screening/scan times, a mobile or ceiling-suspended lead shield should be provided for the staff remaining in the CT room (Fig. 8).

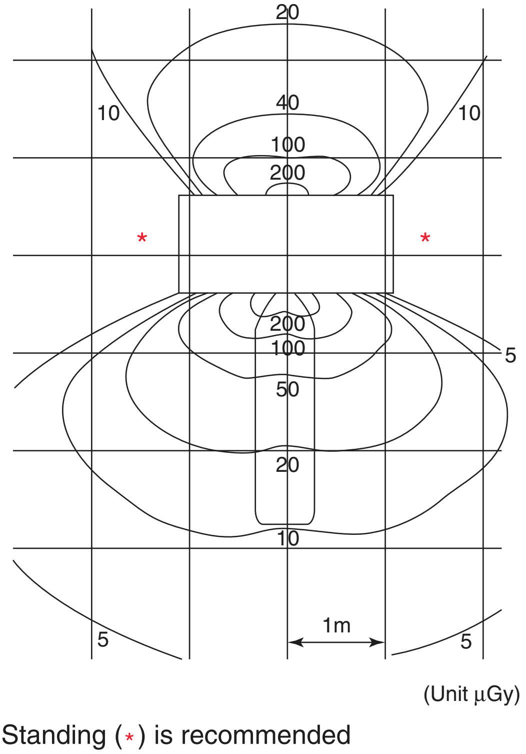
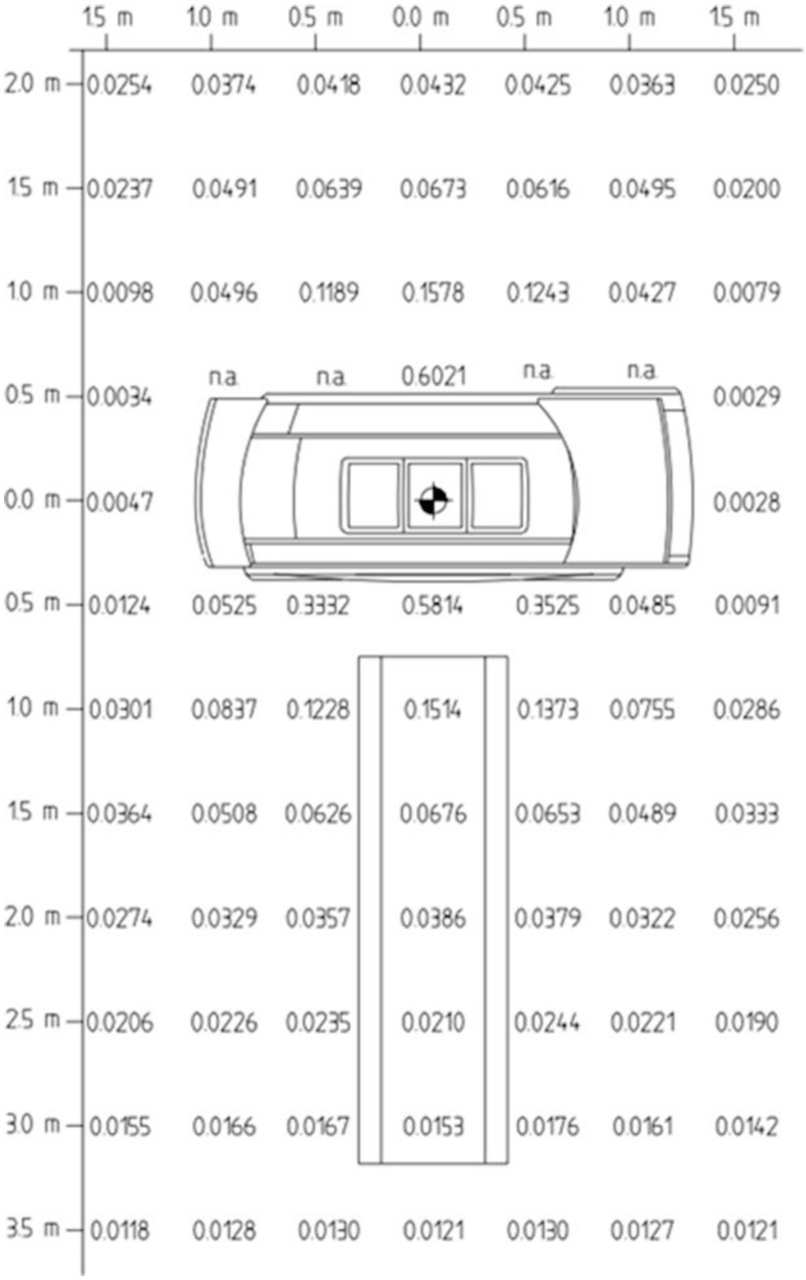


Fig. 4 Recommendation from Canon Medical demonstating area of lowest radiation dose to staff. Image Courtesy of Canon Medical



	1.5 m	1.0 m	0.5 m	0.0 m	0.5 m	1.0 m	1.5 m
2.0 m	0.0254	0.0374	0.0418	0.0432	0.0425	0.0363	0.0250
1.5 m	0.0237	0.0491	0.0639	0.0673	0.0616	0.0495	0.0200
1.0 m	0.0098	0.0496	0.1189	0.1578	0.1243	0.0427	0.0079
0.5 m	0.0034	n.a	n.a	0.6021	n.a	n.a	0.0029
0.0 m	0.0047						0.0028
0.5 m	0.0124	0.0525	0.3332	0.5814	0.3525	0.0485	0.0091
1.0 m	0.0301	0.0837	0.1228	0.1514	0.1373	0.0755	0.0286
1.5 m	0.0364	0.0508	0.0626	0.0676	0.0653	0.0489	0.0333
2.0 m	0.0274	0.0329	0.0357	0.0386	0.0379	0.0322	0.0256
2.5 m	0.0206	0.0226	0.0235	0.0210	0.0244	0.0221	0.0190
3.0 m	0.0155	0.0166	0.0167	0.0153	0.0176	0.0161	0.0142
3.5 m	0.0118	0.0128	0.0130	0.0121	0.0130	0.0127	0.0121

Fig. 5 Horizontal local dose distribution map for Siemens Definition AS 128-slice CT scanner showing that the lowest radiation dose will be received when standing beside the gantry (measurement values in microGy /mAS). Images Courtesy of Siemens Healthineers Australia New Zealand (2021)

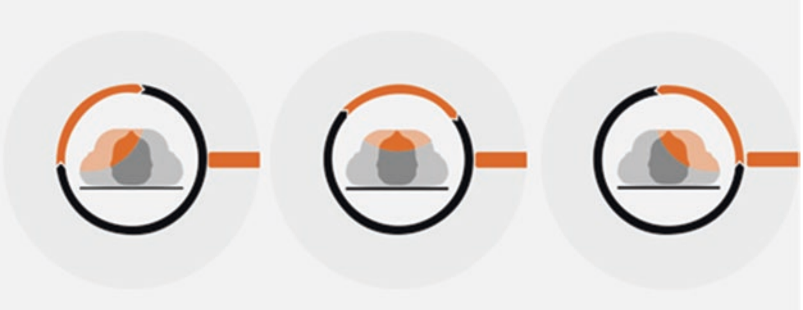


Fig. 6 Siemens HandCARE. Images Courtesy of Siemens Healthineers

Fig. 7 Canon Partial Exposure when the radiologist should stand on the blue side, in this example the left side. Images Courtesy of Canon Medical (Canon Medical Systems ANZ, 2021)

Fig. 8 Photograph of interventional CT set-up with ceiling-mounted protective lead screen. Image Courtesy of Tallaght University Hospital, Dublin

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Part IV

CT Forensic Imaging

CT Forensic Imaging

Edel Doyle and Anthony J. Buxton

Abstract

Forensic CT involves the utilisation of computed tomography (CT) to answer questions of law and can be used in investigations of the living or deceased. With the advent of low-dose protocols, the use of CT in forensic imaging of the living is increasing. Post-mortem CT is frequently used to supplement the invasive autopsy post-mortem examination. It is appreciated that the coroner is ultimately responsible for the post-mortem investigation of all deceased and their permission must be granted for any imaging to occur, as well as for the images to be used in any subsequent publications. Often the agreement of the next of kin is also sought. There are a number of approaches to acquiring post-mortem CT scans, depending on the presentation of the deceased. As the availability and use of post-mortem CT are increasing, additional information can be acquired using advanced imaging techniques to assist the post-mortem investigation such as angiography, CT-guided biopsies or CT ventilation. In living cases, there can be multiple referrers such as the police, border control officers, immigration officers or medical doctors. These are not 'medical' referrals so the justification process for these 'medico-legal' imaging procedures requires a higher level of consideration as the individual does not directly benefit them and therefore informed consent is required. It is important that any radiographers undertaking forensic CT should be appropriately trained in the medico-legal aspects, including local legislation. Training should also be provided so forensic radiographers can recognise the signs and symptoms of post-traumatic stress disorder in themselves and in colleagues.

Keywords

Forensic CT · Legal · Law · Living cases · Deceased cases

1 Introduction

The autopsy is the gold standard in death investigation with imaging used to supplement this examination (Roberts et al. 2012). Whilst it has been proposed that imaging could replace the invasive post-mortem autopsy, this has not been implemented in the majority of jurisdictions and will not occur in cases where criminal charges may be brought about without further supporting research (Varela Morillas et al. 2020).

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The use of post-mortem computed tomography (PMCT) within the field of forensic medicine was first reported in 1977 for the study of gunshot injuries to the head (Wullenweber et al. 1977). The use of PMCT is evolving and it is becoming a common tool for forensic pathologists investigating the cause of death in coronial cases. The 3-dimensional imaging capabilities of PMCT offer many benefits, one of which is the fact that PMCT images are well accepted in court as they can portray the extent of injuries that are not as confronting as forensic photographs of the case.

Involvement of radiographers in a forensic CT service requires detailed knowledge of the image acquisition process to provide images that contribute to the medico-legal investigation and a comprehensive understanding of medico-legal principles including, but not limited to, consent, integrity, continuity of evidence and scope of practice. The CT images produced may be presented as evidence in court and a radiographer may be called to court as a Witness of Fact. Radiographers may also be required to provide a Preliminary Image Evaluation (PIE) or professional review of the CT images to assist the pathologist.

PMCT has proven particularly valuable in mass disaster situations providing large datasets of imaging information that can be reconstructed for use by odontologists or anthropologists to assist in Disaster Victim Identification (DVI) and assist pathologists in establishing the Cause of Death. This all contributes to the final report submitted to the coroner (Dorries 2020; Brough et al. 2015; Mentink et al. 2020).

2 History of Forensic Imaging

Roentgen discovered the "invisible ray" on 8 November 1985 and radiography was first used in a first forensic case on 24 December 1895. CT was first used clinically in 1972 and was used to describe a gunshot wound to the head in 1977 which is acknowledged as the first forensic use of CT (Wullenweber et al. 1977). In the 2000s, the Virtopsy group in Switzerland introduced the concept of using CT in virtual autopsy proposing that it could potentially replace the conventional autopsy (Dirnhofer et al. 2006). In 2012, Roberts et al. concluded that whilst CT was more accurate than MRI in establishing cause of death compared to autopsy, there was no suggestion that imaging should replace the conventional autopsy. Today, CT is often used in forensic cases to assist in answering questions of law, which can relate to either living patients or deceased subjects. CT is often used to triage post-mortem cases to help the forensic pathologist to decide if an autopsy is necessary and may help to limit the extent of the invasive autopsy. For example, if the CT scans of the head and abdomen do not raise any suspicions, the autopsy may be limited to the thoracic cavity with the option available to extend the autopsy if needed.

3 Future of Forensic Imaging

Research groups are constantly testing new technological advances to forensic applications. In specialist forensic centres, PMCT angiography may be undertaken, as it is particularly beneficial in identifying some pathologies that will not be visualised on the invasive post-mortem autopsy such as air emboli. Targeted PMCT coronary angiography is also an option (Roberts et al. 2011), as opposed to whole-body PMCT angiography. When undertaking whole-body PMCT angiography, there are a number of techniques currently in use to administer contrast, including resuscitation, clinical injector pump or a VIRTangio(T) injector pump (Morgan et al. 2014). However, PMCT angiography is not routinely performed in Australia at this time. There are specific considerations when selecting a contrast medium including dilution, water-based contrast or oily-based contrast (Grabherr et al. 2015). The decision to undertake PMCT angiography will be strongly influenced by the next steps in the death investigation process, as the contrast media may affect toxicology results (Robinson et al. 2019a). However, it has not been shown to influence further tests if a targeted PMCT coronary angiography is performed (Rutty et al. 2013). Since the literature review published by (Jayasooriya and Doyle 2019), in the same year (Robinson et al. 2019b) concluded that a PMCT angiography does not add any additional value to the death investigation process in a deceased person with a high PMCT calcium score. It must be noted that these are advanced forensic imaging techniques and additional education is recommended and therefore is beyond the scope of this book (Grabherr et al. 2016).

PMCT pulmonary ventilation of adults and children is also undertaken at some specialist centres but requires additional equipment (Rutty et al. 2016). This technique is used to expand the lung tissue to assist in the detection of subtle lung pathologies (Germerott et al. 2012). It is acknowledged that this approach is not appropriate for use in cases with suspected airborne or droplet diseases. In a situation where there is an outbreak of an airborne disease pandemic, e.g. the COVID-19 pandemic, this technique was suspended.

CT may also be used to guide biopsies or specimen retrieval (Bolliger et al. 2010); again whilst this is not yet common practice in Australia, it is another technique that may be used to help provide additional information to assist in establishing the cause of death (Higgins et al. 2016). CT-guided biopsies can even be performed by robots (Martinez et al. 2014).

Dual energy imaging was proposed for use in forensic imaging in 2013 (Alkadhi and Leschka 2013) with multiple potential applications. It may be used to assist with identifying illicit drugs (Leschka et al. 2013) in the living (Platon et al. 2016; Flach et al. 2011). Spectral imaging will also introduce new opportunities in the forensic setting.

However, all new techniques must be acceptable in court and therefore, it can take time to be accepted in the medico-legal context as the evidence presented in court must meet the required burden of proof, e.g. 'beyond all reasonable doubt', as well as ensuring continuity of the chain of evidence.

4 Living Versus Deceased Cases

CT may be used in living cases for medico-legal purposes, and this requires special consideration of the justification, as there is not a direct health benefit for the individual. Forensic imaging in the living may include non-accidental injury, age estimation or the identification of concealed objects, e.g. drugs, diamonds or weapons. Many radiographers will undertake forensic CT when imaging potential injuries following an alleged assault or road traffic crash. Viner (2006) clarified that it is not necessarily known at the time of imaging that the examination may be the 'subject of a legal action' in the future and that the images produced or the radiologist's report may be required to be presented in court as evidence. Best practice guidelines have been published by the International Association of Forensic Radiographers (IAFR) to ensure that any images produced maintain the chain of evidence and therefore are admissible in court (Doyle et al. 2020).

Imaging to assist with the estimation of skeletal age may be requested in immigration cases to help identify if an individual should be considered an adult or a child, particularly when birth records may not be available. The use of CT when estimating skeletal age has been considered and is not generally recommended in the guidelines published by the IAFR due to the radiation dose implications (Doyle et al. 2019).

Low-dose abdominal CT is recommended over abdominal X-ray as a screening tool for suspected body packers due to its superior sensitivity, specificity and ability to accurately localise drug packets (Lan and Doyle 2019). However, it should be remembered that what may start as a medico-legal case could become a medical emergency should the drug packets rupture. The process of obtaining informed consent from the individual must be thoroughly considered in both of these scenarios. Radiographers involved in forensic CT must be aware of the medico-legal principles and local legislation in respect to the imaging undertaken.

Permission to use PMCT images must be obtained from the coroner so publication of forensic case studies is often rare. As with all medico-legal and forensic cases, details pertaining to the case should not be discussed with people who are not directly involved in the investigation. This is to ensure that justice is achieved, as well as respecting the confidentiality of the deceased and their family.

Figure 1 shows an example of a patient in police custody who was admitted to the ward from the Emergency Department with abdominal pain. He was arrested and detained following a pursuit by police when the car turned back from a routine police checkpoint. When the car was apprehended, it was suspected that there was a quantity of drugs in the possession of the patient. However, he was unable to answer questions when first stopped, as his mouth was full. He was taken to the local police station for further questioning, where he complained of a pain in his stomach. A doctor was called to the police station and advised that the detainee be taken to the Emergency Department so the cause of his abdominal pain could be thoroughly investigated. The patient was referred for an abdominal X-ray and CT.

The patient was transferred from CT to theatre to remove the suspicious packages urgently, as it was concluded that due to his clinical symptoms, it was highly likely that the packaging had ruptured and that he was at a high risk of poisoning. The packages were provided to the police for testing and it is presumed that the patient was prosecuted for the associated criminal charges.

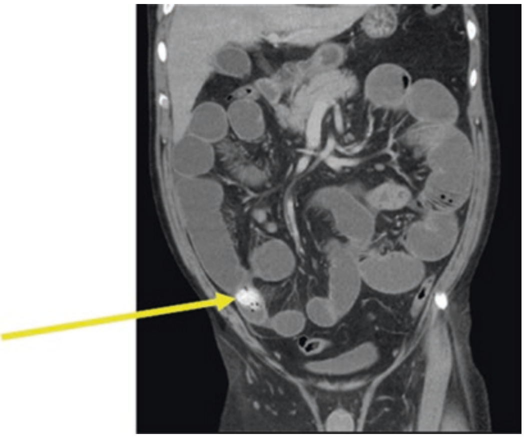


Fig. 1 CT scan of police detainee who developed abdominal pain whilst in custody. The yellow arrow identifies an area of high attenuation density in the distal ileum. Reproduced with permission (Doyle 2009)

CT brain imaging may be undertaken as part of the investigation of non-accidental injury (NAI) or suspected physical abuse in children to identify a subdural haematoma that could be associated with rapid acceleration/deceleration as the result of shaking the child (Radiologists 2017). The detection of post-mortem rib fractures is improved with CT compared to chest X-rays (Shelmerdine et al. 2018). To date, there is no evidence to support the use of CT to replace the traditional series of X-rays in a skeletal survey in living children as part of the NAI investigation, with the exception of the aforementioned CT brain scan.

Radiation protection is a very important consideration when using CT to provide forensic imaging in living people. CT can also be performed post-mortem, with or without the use of intravenous contrast, to help the pathologist and coroner to establish the cause of death. In Australia, the coroner is legally responsible for the identification of the deceased, as well as the investigation surrounding their death. Whilst consent from the next of kin is always sought, if withheld, the coroner may over ride and order that the post-mortem examination proceed. The family can object to the coroner's ruling but this may require a Supreme Court challenge which they would be required to fund and it can be extremely expensive, so generally all efforts are made to support the next of kin to agree. It is important to remember that religious and cultural considerations are always considered but sometimes the law can take precedence, e.g. in the case of homicide. Whilst radiation protection may not be a primary consideration when performing a CT scan of the deceased, radiation output should be considered in terms of extending the lifetime of the equipment.

5 Advantages and Disadvantages of Post-Mortem CT (PMCT)

As a cross-sectional imaging modality, post-mortem CT offers many benefits to forensic investigations. PMCT is non-invasive compared to the traditional autopsy so that the body is not damaged during the imaging process; this can be important to some cultural or religious groups. PMCT provides images that are objective with evidence documented in situ prior to the invasive and destructive autopsy. The CT scans can be reviewed many times, including retrospective review by an independent expert, even after the autopsy has been performed. The acquisition of PMCT scans is relatively quick compared to the time taken to perform an autopsy, making it quite useful in the identification of deceased in mass disasters such as the MH17 terrorist incident (Hofman et al. 2019).

Forensic imaging is accepted and recognised internationally as an integral part of the DVI process (Interpol 2009) and includes radiography, dental x-rays, fluoroscopy and CT (Doyle et al. 2020). Forensic imaging involves the application of diagnostic imaging techniques to answer questions of law. Forensic imaging techniques have been stated to benefit the post-mortem investigation because the techniques are 'minimally invasive, objective, permanent and comparatively cost-effective' (Viner 2008). As much research has focussed on the effectiveness of PMCT as a replacement for the traditional autopsy, it has been argued that that PMCT can successfully acquire all necessary radiological information, thus eliminating the need for radiography (Sidler et al. 2007; Rutty et al. 2007; Rutty et al. 2009). Other authors (Jeffery et al. 2008; Roberts et al. 2012) have stated that PMCT cannot provide the same level of information compared to a traditional post-mortem examination and that the detailed information provided by PMCT cannot replace the 'external inspection and internal examination of the deceased by an experienced observer' (Thali et al. 2003b). While PMCT is being used more frequently (Mahmood 2013; Thornton 2013), it is as an adjunct to the invasive autopsy, rather than as a replacement (Roberts et al. 2012; Higginbotham-Jones and Ward 2014). Recently, PMCT has been utilised to increase the speed and accuracy of imaging in the forensic investigation of a Mass Fatality Incident (MFI) (Rutty et al. 2007; Levy and Harcke 2011). It has been stated that 'today cross-sectional imaging has an established role in mass fatality incidents across the world' (NHS Implementation Sub-Group of the Department of Health Post Mortem 2012, p. 35) but the post mortem, forensic and disaster imaging (PMFDI) Group did not describe or quantify the extent of the role of PMCT in the DVI process. In Australia, PMCT is routinely used in Victoria and New South Wales with access to PMCT facilities available in Queensland, South Australia, Tasmania, Western Australia, the Australian Capital Territory and the Northern Territory.

5.1 Strengths of PMCT

A cross-sectional imaging modality such as CT allows for complex data to be acquired in minutes and then to be reviewed in an easy and interactive format (Thali et al. 2003a). The acquisition of a whole-body PMCT scan takes '10–15 min per body' (Sidler et al. 2007). From a forensic perspective, Webster (2010) emphasised that the contents of the body bag can undergo PMCT scanning without the bag being opened, thus ensuring the integrity of the chain of evidence. This also facilitates the exploration of both anatomy and injury patterns in a non-invasive and non-destructive manner (Thali et al. 2003a; O Donnell 2010; Morgan 2010). The detailed information that can be acquired by PMCT may reduce the number of cases where resection of body parts such as the mandible are considered necessary, thereby avoiding further distress for the bereaved families (Forrest 2012).

The CT raw data provides permanent documentation as well as facilitating the reconstruction of 3-dimensional (3D) images, compared to the limited 2-dimensional (2D) images produced by conventional radiography. PMCT generates digital data that is observer-independent and non-subjective (Thali et al. 2003b). This data can be efficiently and effectively stored and is easily transferred electronically if a second opinion is required (Thali et al. 2003b; Leth 2009), thereby minimising the number of professionals required in the Emergency Mortuary (PMFDI Group 2012). In forensic scenarios, the security of the storage system must be assured so the data can be produced in court as evidence in the form of ‘photos’ or ‘videos’. The post-processing steps performed must have been reproducible and there must have been an audit trail of any changes. Reconstructed multi-planar images from PMCT have the advantage over photographs of being more visually acceptable for non-medical personnel, including family members and the jury in court (Gibb 2008).

5.2 Limitations of PMCT

The disadvantages associated with the use of PMCT include limited access to CT scanners and the cost of purchasing or leasing such equipment in the event of a mass fatality incident (MFI) or mass disaster (PMFDI Group 2012). PMCT documentation of dental restorations is inferior to the description acquired from the visual dental survey, particularly due to the lack of colour information required to differentiate types of restorations (Kirchhoff et al. 2008). The experience of radiologists in reviewing post-mortem changes and of pathologists in reviewing cross-sectional images is improving but is still a limiting factor in maximising the potential of forensic CT imaging (Royal College of Radiologists (RCR) and Royal College of Pathologists (RCPath) 2012).

When required for a medico-legal case, the raw data for the relevant PMCT scans has to be stored in a manner that will permit further data reconstruction to be performed at a later date (The Society and College of Radiographers and The International Association of Forensic Radiographers 2010).

Streak artefacts may be caused by metallic artefacts in the scan field of view. There are several regions examined using PMCT that are of areas where metal artefacts seriously degrade the resultant images, such as the pelvis when the patient has a hip/s replacement. The most difficult area to examine using PMCT is dental reconstructions as part of the process of patient identification in the severely decomposed and DVI incidents.

Imaging can be obtained using very thin slice acquisition and the application of single energy metal artefact reduction or dual energy metal artefact reduction post-processing software packages (Kawahara et al. 2019; Chandrasekar et al. 2020). Some CT scanners are capable of undertaking DEMAR with a single tube which switches kV or by using a scanner with dual X-ray tubes. Access to this technology or even the software for SEMAR may not be available to all centres so the use of multiple pixel thickness Multi-Planar Reconstructions (MPR), generally as a pseudo OPG is often the most helpful approach especially if the volume used contains information about the sinus outlines (Forrest 2019). In the scenario where MAR software or algorithms are not available on the local CT scanner, if the gantry can be angled to exclude the metallic objects from the scan field of view, this is an alternative option of reducing streak artefacts.

6 PMCT Protocol Considerations

6.1 Equipment

Technical parameters of the scanner being used is beyond the scope of this chapter, however consideration of the optimal parameters is an essential aspect of the scanning capability of the scanner being used for PMCT (Gascho et al. 2018). The important consideration is that the scanner must be capable of reconstructing images in the axial, coronal and sagittal planes, so the reconstructions should be made with overlapping slice thicknesses. If the scanner is not capable of isotropic image acquisition (considered to be 0.5 mm), then the use of a negative pitch is recommended (Tsukagoshi et al. 2007).

6.2 Reconstruction Considerations

All images should be reconstructed using both a contrast (soft) and spatial resolution (hard) algorithm for all three planes, in order to visualise both soft tissue and bone structures. Thick slices stored on a PACS system should be a minimum of 5 mm thick with 5 mm spacing, however 3 mm × 3 mm is preferable if storage capacity is not an issue. The availability of surface shaded rendering of the region is also an advantage to enable an overview of the anatomy being investigated. It is recommended that each volume dataset is saved to the PACS due to the possibility that the raw datasets may be subpoenaed for a court of law.

The most relevant consideration in the purchase of a scanner dedicated to PMCT is the bore size and to this end, the larger the better, to allow for cases that are hypersthenic, extensively dilated due to decomposition or disfigured such as a burns presentation. The consideration of extended field of view reconstruction often used in radiation therapy and dual energy capabilities are also important (Cheung et al. 2019). Other important considerations are maximum weight of a case and the length of table travel.

6.3 Scanning Approaches

6.3.1 General Considerations

The extent of imaging undertaken depends on an established departmental protocol, and the information provided here addresses ways to address this consideration. The primary consideration is the service expectations of the role of PMCT in the service delivery, for example it is to be used just to image a specific region of the body to assist in diagnosis/confirmation of a cause of death or as a permanent record of the case to be kept on file. Ideally, the scan should be used to provide assistance to the forensic pathologist in regard to the identification and cause of the death of the presenting case, however it can also be used to identify comorbidity conditions that add to the clinical picture. This role should be clearly identified when setting up the PMCT service.

The use of PMCT which may be only to provide information relevant to the case presentation or as a formal record forming part of the final case record. The use of a targeted study of imaging only the relevant region/s of the body to confirm the cause of death has the advantage of reducing wear and tear on the scanner in particular the tube life. The disadvantage of this approach is that comorbidities, which may be relevant in the patient demise, are not identified and there is no permanent record of soft tissue anatomy of the case.

The overriding consideration in regard to the use of the PMCT delivery is always governed by the Coronial Act of the service jurisdiction, and the most fundamental concept here is the adoption of the least invasive approach to the identification of the identity, time and cause of death. The minimum recommend approach of a study would be a head, neck and torso examination with only the limbs excluded.

6.3.2 Study Approaches

Head, Neck and Torso

This examination involves a volume acquisition from above the vertex of the skull to the sternoclavicular joints and then another volume acquisition from above the shoulders to mid femur. The consideration being to ensure all abdominal contents are included along, where possible, with the skin line being visible, and for males to include the external genitalia. An important consideration here is the location of the arms for the torso acquisition. Ideally the arms should be raised above the head but this may not be possible due to department protocol about opening body bags and if the case must be scanned closed due to a suspicious nature of presentation. There is always a risk of post-mortem trauma to the body in “breaking rigor” incorrectly. The disadvantage of scanning the case with the arms by the side is the possibility of beam hardening artefacts from arms outside the scanned field of view. The use of a large bore scanner can alleviate this to some degree as can the use of mummification (tightly wrapping the bag to the body with tape) or carefully placing the arms as anteriorly over the torso as possible (even through the bag).

The scan acquisition for the head and neck should use the minimum slice thickness available in conjunction with a negative pitch and reconstructions performed with a minimum of 30% slice overlap. For example, in the case of an isotropic capable scanner, the acquisition should be 0.5 mm slice thickness with a 0.3 mm slice interval and the images reconstructed at a minimum of 3 mm × 3 mm in all three planes. For the torso, images 1 mm thick with a 0.8 mm interval should be acquired and reconstructed with the same slice thickness, e.g. 1 mm × 1 mm. Figures 2 and 3 are soft tissue reconstruction examples.

Whole-Body Approach No 1

The study starts with the head and neck protocol previously described. The second acquisition which is very dependent on the table travel length is to scan from above the head to below the toes, which some scanners may not be capable of performing. This acquisition is using the torso parameters of thin slice acquisition. A modification that can be undertaken is to only scan from above the shoulders to below the toes. The head acquisition is not to be used for diagnosis, but it is often appreciated by the forensic pathologists due to the ability to obtain a full body 3D render of the case, especially if serious disfiguration has occurred. This acquisition does result in a very heavy heat load to the scanner and over time will reduce tube life. Tube cooling between acquisitions and or cases also becomes a consideration apart from the fact that potentially up to 8000 slices will need reconstructing. Again, arm placement is a consideration and the recommendation is that if possible the arms are kept by the side or on the abdomen (to reduce beam hardening artefact). It is generally not possible to scan the entire body with the arms above the head.

The acquisition is acquired with a slice thickness of 1 mm and a 0.8 mm interval with reconstructions for reporting being 3 mm × 3 mm. Figure 4 demonstrates the soft tissue reconstruction example.

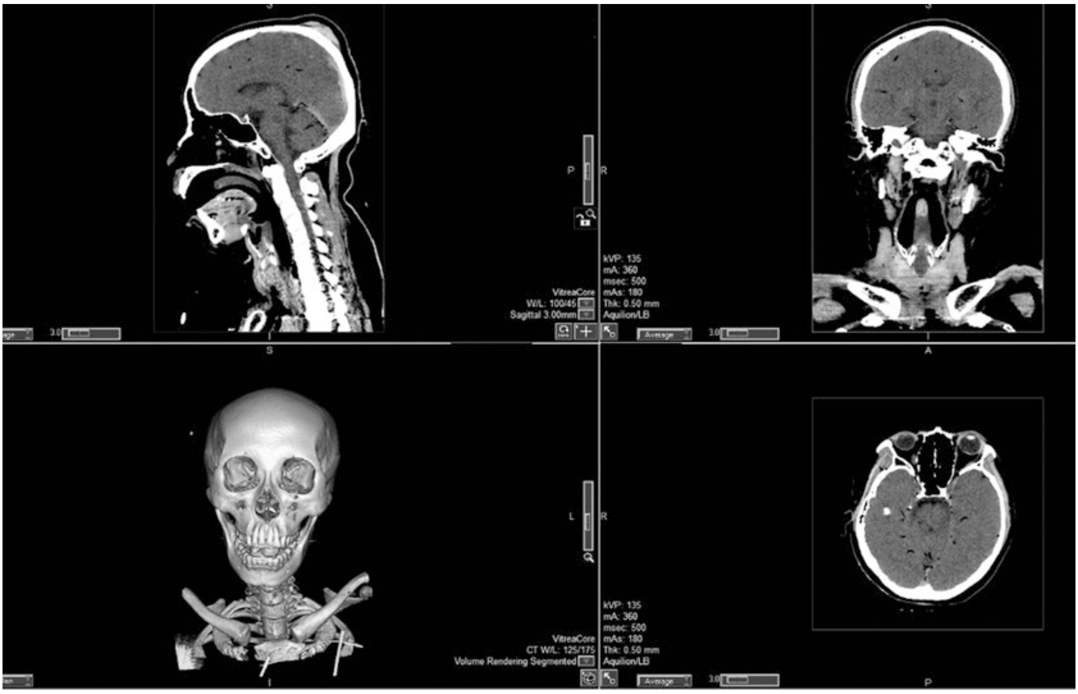
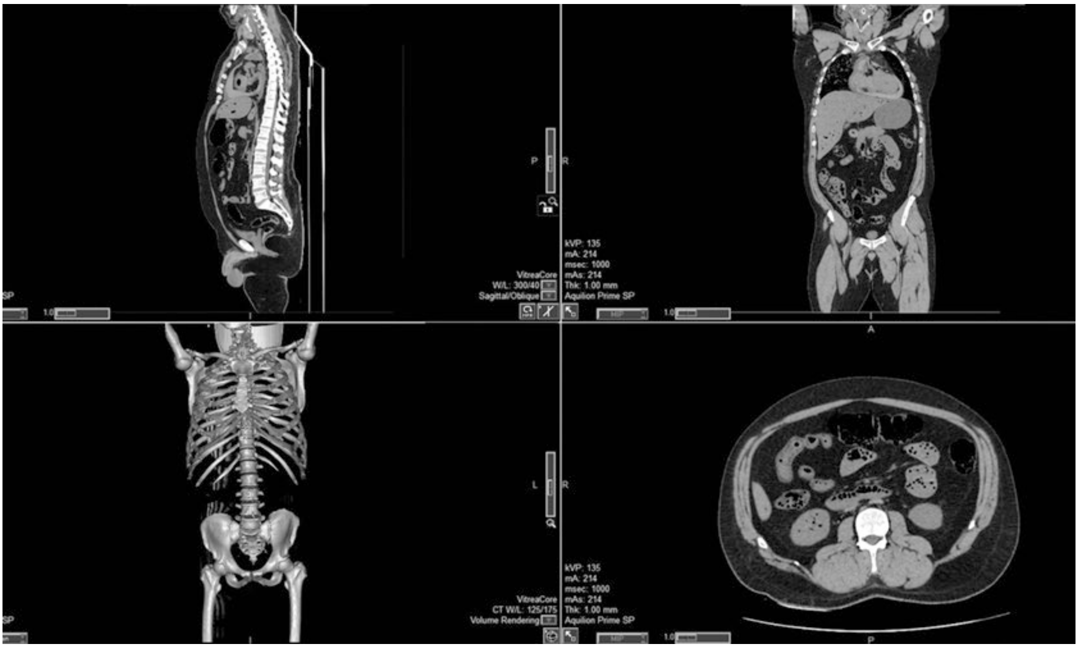


Fig. 2 Soft tissue MPRs for CT head & neck



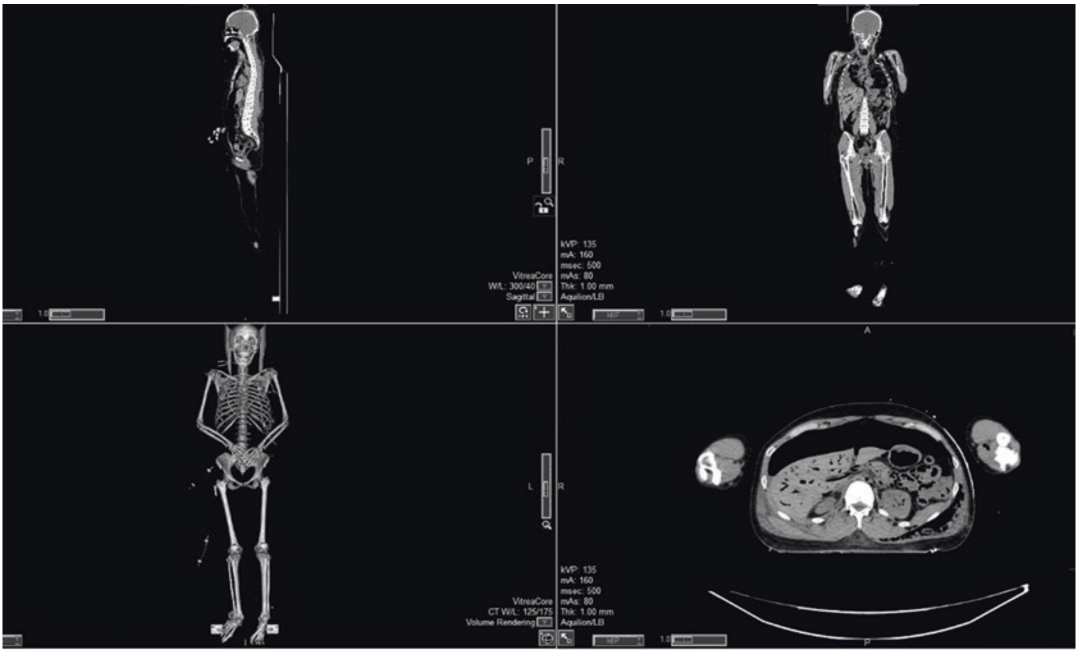
VitreaCore
W/L: 300/40
Sagittal/Oblique

kVP: 135
mA: 214
msec: 1000
mAs: 214
Thk: 1.00 mm
Aquilion Prime SP

VitreaCore
CT W/L: 125/175
Volume Rendering

kVP: 135
mA: 214
msec: 1000
mAs: 214
Thk: 1.00 mm
Aquilion Prime SP

Fig. 3 Soft tissue MPRs for CT torso



VitreaCore
W/L: 300/40
Sagittal

kVP: 135
mA: 160
msec: 500
mAs: 80
Thk: 1.00 mm
Aquilion/LB

VitreaCore
CT W/L: 125/175
Volume Rendering

kVP: 135
mA: 160
msec: 500
mAs: 80
Thk: 1.00 mm
Aquilion/LB

Fig. 4 Soft tissue MPRs including SSD for CT whole body

Whole-Body Approach No 2 (Recommended)

This study again starts with the recommended head and neck acquisition. This is then followed by the torso study; however, the arms must be beside the body or over the abdomen, so they are included as part of the study. A third acquisition is then undertaken from above the acetabulum to below the toes. A major advantage of this acquisition is that if the case is too long for the table movement to cover the entire body in a single run, the case can be moved along the table (some turn the body around on the table, but this is not recommended). The distal limb acquisition is obtained using a slice thickness of 2 mm and 1.5 mm interval with reconstructions for reporting being 3 mm × 3 mm.

6.3.3 Dental Acquisition

Most scanners have a protocol for metal artefact reduction reconstruction (optional cost generally). A scan acquisition using the thinnest possible slice thickness with at least a 30% overlap is recommended and employing an ultra-high spatial resolution reconstruction algorithm. The scan range is from above the mandibular fossa to below the mandibular symphysis with the isocentre mid-way between the angles of the mandible. Curved MPRs to simulate an OPG are ideal with reformations starting at 1 mm thick up to 20 mm. Dental package acquisitions and reformations are not necessary as such antemortem imaging is less likely available compared to OPG and/or bite-wing imaging. Mobile dental imaging using a Nomad hand-held dental X-ray unit is usually performed if dedicated intra-oral imaging is required. However, pseudo bite-wings made be reconstructed using a curved MPR approach.

6.3.4 Choice of Scan Approach

The decision to proceed with PMCT is driven by the clinical presentation of the case and the forensic pathologist triaging the case. The individual forensic pathologist may have a specific examination approach. It is recommended that a consistent service approach for the development of a recommended scan guideline per case presentation provides more uniformity across the service (Table 1).

Table 1 NSW health pathology, forensic medicine CT scanning guideline

Case presentation and recommended study approach	
Full body	Head, neck and torso
Death in custody	Sudden death of a presumed natural causes
Homicide/suspicious	Complex hospital referral
SIDS/SUDI (include full body X-rays)	Morbidly obese
Decomposed (with or without dental scan)	Maternal deaths
Incinerated (include dental scan)	Hospital deaths **with extensive medical history**
Industrial accident	Suicides—hanging, self-inflicted GSW, CO poisoning
Diving accident	Drug overdose (excluding suspected IV drug user)
Aviation accident (with or without dental scan)	Witnessed drownings
Other paediatric cases	
Transport related incidents (with or without dental scan)	
Skeletal remains with residual soft tissue	
Suspected intravenous drug user (possibly include bag looking for sharps)	
Unwitnessed drownings	

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7 Image Storage, Retrieval & Archiving

As CT may be used for the forensic imaging of live or deceased subjects, the international best practice guidelines published by the International Association of Forensic Radiographers (IAFR) aim to outline the role of radiographers involved in such situations and to ensure that correct procedures are followed without compromising the voluntary nature of the work Doyle et al. (2020). Even though it is not necessarily known at the time of imaging that the examination may be the "subject of a legal action" in the future, radiographers should be aware that the images produced or the radiologist's report may be required to be presented in court as evidence. Brogdon (1998) noted that X-ray images were presented in court and admitted as evidence, as early as 1896. He stated that the 'admissibility of the product of a radiological examination is unlikely to be questioned in a modern courtroom. There may be a requirement to show that it was obtained by an accurate and generally recognised methodology and accurately represents the object investigated'. Blitzer et al. (2008) discuss that 'digital photographs offer a new set of authentication issues for the court, since they can be more easily manipulated, altered or enhanced'. Therefore, it should be realised that it may be necessary that the radiographer attend the court as an expert witness and describe the processes involved in acquiring the CT scan.

7.1 Discussion of Medico-Legal Concepts

Evidence presented in a legal case could include the CT images themselves, or the report issued by the radiologist and either, or both, of these may be produced in court as evidence. The court may summon expert witnesses, which in this case could be the radiologist and/or the radiographer. The purpose of an expert witness has been outlined by the Federal Court of Australia (n.d.) in the 'Expert Evidence Practice Note' (GPN-EXPT):

> *the use of expert evidence in proceedings, often in relation to complex subject matter, is for the Court to receive the benefit of the objective and impartial assessment of an issue from a witness with specialised knowledge (based on training, study or experience - see generally s 79 of the Evidence Act).*

Whilst the Federal Court of Australia acknowledges that

> *An expert witness' opinion evidence may have little or no value unless the assumptions adopted by the expert (i.e. the facts or grounds relied upon) and his or her reasoning are expressly stated in any written report or oral evidence given.*

Even in this scenario, the radiologist who produced the radiology report may be required to explain the results of the CT scan to the court and jury in layman's terms. The radiographer who produced the images, on which the radiologist's report was based, may also be summoned to explain the process involved in acquiring the images and to confirm the continuity of the chain of evidence (i.e. the images) from the time they were taken to the time they were given to the police.

The IAFR guidelines clearly describe procedures to ensure continuity of evidence when producing digital images Doyle et al. (2020). The IAFR guidelines clearly state that in order for evidence to be admissible, it must be.

> *properly authenticated and continuity of evidence must be demonstrated. The Radiographer, supported by an appropriate witness should be able to attest in court of law that any specific image was produced by them at the date and time indicated, that the image is of the identified evidence and has not been tampered with during, or as the result, of the image production process.*

Viner stated that it may be argued that digital images are more secure because '*any change to image data is/or can be recorded so that any evidence of tampering can be detected'* (The Society and College of Radiographers 2006). PACS records some manipulations that are made to the images (e.g. rotating an image 90°) but not all (e.g. flipping an image from right to left) which means that there is an incomplete electronic record of changes made to the image. Berg (2000) stated that '*any enhancement applied to an image must take place on a copy of the original'*. Therefore, the original image (i.e. the Master copy) acts as a 'control' and documented enhancements can be easily reproduced. This process is clearly described in the IAFR Guidelines when undertaking forensic imaging examinations (Doyle et al. 2020). It should be the aim of

> *any effective image-tracking procedure to eliminate the opportunity for unauthorized persons to access images, thus avoiding the argument that someone could have altered or substituted an image* (Berg 2000)

The department thus needs to demonstrate that a

> *robust and secure method of image storage, transmission and control of access to images is in place, and normal procedures that exist for medical confidentiality should be sufficient* (The Society and College of Radiographers 2006)

8 Radiographer Review/Impressions in PMCT

8.1 Background

Most of the literature available on radiographer reporting is addressing the current clinical environment and in Australia the objection to such practice by the RANZCR (Woznitza et al. 2021). Indeed, this role extension has been a topic of debate and discussion for over 30 years. There is support for this role from the radiographers and a majority lack of support from radiologists, certainly in Australia (The Royal Australian and New Zealand College of Radiologists 2018). The UK, with the NHS, has a different structure to Australia (even North America, USA and Canada) whereby advanced practitioner reporting radiographers, with a clearly defined scope of practice, are recognised.

In Australia, the MRPBA has stated in its professional capabilities document that offering an opinion on imaging obtained by the radiographer is not only within their scope of practice but is also a professional responsibility in regard to a quality service delivery (Medical Radiation Practice Board (AHPRA) 2020). A major consideration, certainly in Australia, is the fact there is no rebatable item number from Medicare (Health Insurance Commission) for a PMCT study, and therefore radiologists employed by forensic services are remunerated on a sessional basis or on a negotiated set fee per study basis. There is also a shortage of radiologists resulting in a limited pool of them with specialist forensic radiology skills. The international position is most likely reflective of this situation. The reliance of the use of IV contrast in clinical practice and the changes that take place in the human body after death add to the complications in reporting on PMCT cases. This results in the need to selectively refer cases for a radiology report and that means cases of a complex nature, that may result in a coronial enquiry, are generally the only cases referred for a formal radiology report. There is also a strong belief that forensic pathologists have the skills and knowledge to evaluate the PMCT (International Society of Forensic Radiology and Imaging 2020). This combination of circumstances has resulted in an ad hoc approach to just how the images obtained in PMCT are managed.

There is no doubt that PMCT provides valuable information on the anatomy and pathology of a deceased person, however there is a disconnect between how the anatomy and pathology appear in imaging compared to the actual anatomical structure at post-mortem. Imaging relies on the density of anatomical/pathological structures to provide information on what is seen, and this appearance is not so evident on anatomical specimens. Imaging appearances post-mortem must be learned so that post-mortem artefacts can be identified from pathology (Sutherland and O'Donnell 2018). In PMCT a brain tumour, even without contrast, is often very easily identified due to subtle tissue density changes and possible surrounding oedema, however the gross anatomy appearance is considerably different. Similarly, many subtle cranial abnormalities, not identified on PMCT, are clearly identified during a post-mortem examination. Therefore, this correlation between actual anatomical/pathological appearance and the representation of the same information on a PMCT are very dissimilar, and there is a steep learning curve for the forensic pathologist to correlate their gross anatomy visual skills to PMCT appearances. Many enjoy this challenge and become expert in the role. The majority however do not have the time or the necessary regular exposure to PMCT to gain the confidence to correlate the clinical information, which includes PMCT, into their workload. To them the addition of the availability of an impression of the PMCT, by someone with imaging experience, as part of the medical records they review is of greater benefit and less time consuming.

The next issue that needs to be addressed is the justification of allocating limited radiology reporting time to all PMCT cases. There is anecdotal evidence to suggest that coroners are increasingly relying on the information provided in a PMCT to support the forensic pathologist recommendation for the allocation of a coroner's certificate without the need to proceed to autopsy, or indeed the need for only a limited post-mortem examination. Most centres currently rely on specific cases going directly to a formal radiology report and the remainder having a limited “skim” by the forensic pathologist who may have sufficient information to identify a legally acceptable identity and cause of death in a case. The PMCT then just becomes a part of the case file along with other clinical tests, both ante and post-mortem.

Finally, radiologists may not necessarily be interested in reporting on all PMCT cases for a number of reasons:

1. There are just too many and insufficient hours allocated to the task thus impacting on addressing more important case reports.
2. A formal report, which is legally binding, must address the entire anatomy/pathology of the case and not just describe a cause of death pathology so potentially are time consuming.
3. The majority of cases may present with obvious pathology which would not require a detailed radiology report and basically an inappropriate use of radiologist time.

With this background, the extension of the role of a radiographer in supporting the forensic pathologist by providing a review or impression of the PMCT provides a valuable service and increased job satisfaction for the radiographer. This approach is described by the Australian Society of Medical Imaging and Radiation Therapy as ‘Preliminary Image Interpretation’ and is not intended to replace a radiologist's report.

8.2 What Is a Radiographer Review/Impression?

One of the strengths of a radiographer is their ability to pattern recognise. From daily observation of the imaging they produce, radiographers develop the ability to identify normal from abnormal anatomical structures as they appear in medical imaging. This skill can be translated to a more formalised structure whereby the radiographer provides a written comment on the PMCT to assist the forensic pathologist correlate other clinical information in order to progress the triaging and final management of a case.

The arrangement needs to be structured and supported by all parties, up to and including the coroner. The review then becomes a part of the final case record. Although having no legal standing, the information can be used for the forensic pathologist to decide whether a radiology report should be requested. The major advantage of the implementation of radiographer review is that all cases presenting to the coronial service can be imaged, and a review forwarded to the triaging forensic pathologist in a very short time frame to allow for the case to move potentially more swiftly through the coronial process.

8.3 The Structure and Approach for Radiographer Reviewing/Impressions

The primary role of the radiographer review is to identify a likely Cause of Death (CoD) in a patient. In the case of an obvious cause not being identified by the radiographer, comment should be made regarding any potential abnormality, which in conjunction with the detailed clinical history the forensic pathologist has, may assist in formulating the management strategy. For example, the identification of the absence or presence of coronary artery calcification which may or may not have resulted in the patient's death. A role in patient identification can also assist the coroner.

A suggested approach is to divide the case into regions. Prior to making any comment, the radiographer should look at all images in the axial, coronal and sagittal plane, often starting by looking at a 3D rendered image of the skull and cervical vertebrae and then the entire body. A basic understanding of why the case has become a coronal referral gives an insight into the possible pathology that may be identified.

8.3.1 Head and Neck

The head and neck are viewed in all three planes using two window settings: soft tissue (contrast algorithm) and bone (spatial resolution). Careful observation of the vascular structures looking for vessel calcification or dilatation. The symmetry of the brain and ventricles as well as identification of atrophy inconsistent with age. The presence of air (decomposition or trauma), blood traumatic or spontaneous and other incidental findings such as basal ganglia calcification. Basal ganglia microcalcification is a frequently identified anomaly, such as the identification of calcification in, or near, the falx. However, mentioning this fact may be relevant to the forensic pathologist who has a clinical history of the patient suffering from Fahr's syndrome and this information can assist in several ways, including confirmation of the case's identity. The radiographer then looks at all three scan planes using a high spatial resolution (bone) window to identify any bony abnormality. In the case of a substantial head injury, the radiographer can simply indicate 'extensive trauma to the majority of the bones of the vault (and neck)' whereas a radiology report would be obliged to provide more detailed description if there is a possibility of the case being part of a coronial judicial enquiry. Cervical alignment, medical intervention appliances and any artefact not necessarily expected to be seen should be documented. In the situation of a gunshot wound, the track and location of projectile fragments are helpful, along with any other software manipulation that can provide more detailed information on the projectile fragments (Fig. 5).

8.3.2 Chest

The chest is viewed in all three planes using three different window settings: soft tissue, bone and lung (spatial resolution with a wide window and lung tissue level). The heart is observed for cardiac size and the level, if any, of calcification, both vascular and cardiac valves. The pericardium and thoracic aorta are also reviewed, and the level of vascular calcification noted. Indication of the presence of an implanted medical device (pacemaker or defibrillator, the exact type is not important just the existence) is important and generally the body bag will then have a warning sticker applied, if not already there. The hilar structures and the pleural walls are examined looking for lymph node enlargement, calcification plaques and any lung soft tissue or fluid collections. Hounsfield unit readings (looking for comparison between soft tissue collapse/consolidation and fluid which are similar to antemortem non-contrast studies) are taken of pleural collections to exclude the likelihood of blood or infective material.

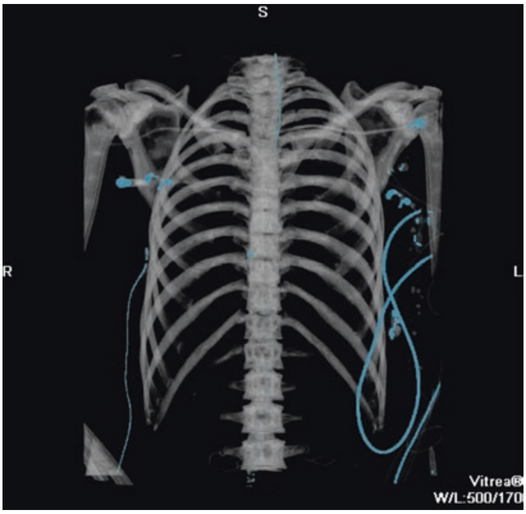

Fig. 5 Screenshot using 'blue metal' algorithm which highlights ballistic material present, as well as the ECG leads that are still in situ

It is important to recognise the changes that occur in the accuracy of HU readings over time. Zech et al. (2014) identified that during 1–4 days post death interval, the HU reading was similar to the known values for those regions in the living. However, once putrefaction is a factor this makes the reliability of these HU readings variable, as the influence of putrefaction fluids reduces reliability. They also stated that the beam energies used, and the body temperature had only minor influence on HU value ranges and therefore in the early stages of post-mortem should not complicate the differentiation and characterisation of body fluid and blood. Andrews (2016) also stated how important it is to consider the influence of purification when interpreting PMCT imaging.

The location in situ of and medical devices such as an intubation/endotracheal tube or nasogastric tube are checked for correct position, particularly the end of the intubation tube to be located within the trachea and above the carina. A hiatus hernia of clinical significance should be noted. The lung window is used to identify the presence of a pneumothorax, small interstitial abnormalities such as infiltrative disease, the presence of any Chronic Pulmonary Obstructive Disease (COPD), including bullae and air bronchograms or entrapment. The bone window is used to identify any calcium in consolidated areas of the thoracic aorta, lung and/or the pleural wall, rib fractures, sternal integrity and thoracic spine degeneration/trauma.

8.3.3 Abdomen

The abdomen is viewed in all three planes using three different windows settings: soft tissue, bone and lung. The choice of using a lung window is dependent upon case presentation, for example identification of level of decomposition or possibility of perforation. In the case of suspected liver disease often the liver is viewed in a narrow window (WW80/WL80) looking for subtle liver disease. HU readings should be taken of the liver and spleen in any case where the two structures appear to have differing densities on first review. The organs of the abdomen are observed for size, composition and location. The identification of gallstones or cholecystectomy clips is an important observation, which may assist in confirming the identification of the deceased. Any medical devices need to be identified and if correctly is situ, such as NG tubes, drains from surgery, feeding tubes, supra-pubic and direct bladder catheters, and stomas. Vascular size and level of calcification should be noted along with incidental findings such renal calculi/cysts and high attenuation residue in the stomach or bowel (N.B. Identify as high attenuation residue and not try and be specific). Stomach and bladder size should be commented upon if distended. Bowel distention and numerous fluid levels should be identified but not stated as obstructive, this will be correlated by the forensic pathologist. Any foreign material (e.g. projectiles or surgical intervention) and the integrity of the skin should be noted. The uterus and prostate should be noted as unremarkable. For the uterus if bulky, indicate the level of homogeneity and for the prostate, indicate if hyperplastic and the level of calcification, if any. Ascites, fresh and/or old blood and air identified or excluded. The spine is viewed for any abnormality and level of degeneration can be noted.

8.3.4 Limbs

The value of CT of the limbs is still being evaluated, and certainly projectional radiography provides a higher level of spatial resolution to CT. The limbs should be view in all three planes using both the soft tissue and bone algorithms/windows (contrast and spatial algorithms and viewing window and level). Any disruption of the skin, e.g. burns or trauma, should be noted and identification of any obvious skeletal damage or disease documented. In the case of intravenous (IV) drug presentations, care is taken to ensure no obvious sharps are present. The absence or presence of any should be noted in the review.

When writing a radiographer review, it is important to remain within the scope of practice as defined by the MRPBA professional capabilities (2020). For example, in the case of a possible oral drug overdose, the review should describe ‘high attenuation residue is noted in the stomach, some of which is rounded and most layering posteriorly’, rather than stating ‘Tablet residue is noted in the stomach’ as many food products, e.g. chick peas, are rounded and appear as high attenuation material in the stomach. The fact the radiographer has identified the stomach contents contain high attenuation material allows the forensic pathologist to decide if this is consistent with the ingested products or whether examination of the stomach contents at PM is warranted. A more common example is the noting of calcific pleural and pericardial plaques. This may represent asbestosis, but it also may be related to calcification from tuberculosis, information that the forensic pathologist may have access to which will confirm the diagnosis, or again proceed to PM, therefore the review just identifies the presence of the calcific plagues and where they are located.

9 Education and Training

The International Association of Forensic Radiographers recognise that forensic CT is not a graduate competency (Doyle et al. 2020). It is highly recommended that additional education and training are completed prior to undertaking any forensic imaging. A thorough knowledge and understanding of medico-legal principles, as well as relevant legislation, are required. This includes understanding the challenges associated with maintaining continuity of evidence and obtaining consent in living patients.

Forensic CT may be distressful for some people and should only be performed on a voluntary basis, unless specifically employed in that role. It is very important that forensic radiographers are trained to recognise and identify the signs and symptoms of post-traumatic stress disorder (PTSD). This is a significant consideration for managers, as a timely debrief and on-going support processes must be available, even long after critical events, as unrelated situations may trigger PTSD.

10 Conclusion

The use of CT in forensic and medico-legal cases, especially PMCT, continues to develop. PMCT plays a role in death investigation and often helps reduce the need for invasive autopsies. It also provides an opportunity for radiographers to extend and apply their knowledge and skills in helping to answer questions of law whilst remaining within their scope of practice. One of the most important aspects of radiographer reviewing is to act within the scope of practice by describing what possible abnormality is identified and not try and classify it as a specific condition.

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Part V

CT Education

Education in CT

Andrew Kilgour

Abstract

Optimising education of medical radiation science practitioners in the art and science of Computed Tomography (CT) requires an understanding of the fundamental principles of education. These generic principles of learning include andragogy (adult learning) and pedagogy (the method and practice of teaching). When applied, these principles give a platform to the principles which are specific to medical radiation science education. This platform can be built on to teach the skills that are specific to becoming a proficient and capable CT practitioner. These educational principles must be seamlessly integrated with the professional practice of CT, so that adult learners can absorb them in an authentic environment.

Integral to teaching is assessment, determining whether the knowledge imparted has been absorbed, and importantly, whether the learner can apply this knowledge to their practice. It is important that we assess capability rather than competence, so the fundamental differences between capability and competence will be discussed. Assessing a practitioner's capability in the requisites of CT involves the principle of assessment for learning, rather than assessment of learning. Assessments of capability in CT can be designed to be implemented as a learning experience for these practitioners, rather than just a requirement to allow them to be considered capable.

CT is considered part of a radiographer's scope of practice; however, students do not graduate from undergraduate radiography degrees fully capable in CT. They may understand the theory and have some experience of clinical practice under supervision, but they are not capable of working independently as a CT radiographer. As these graduates are adults, a self-directed learning program, acknowledging prior experiences and knowledge, will maximise the learning program offered.

Keywords

Adult education · Andragogy · Pedagogy · Competence · Capability · Dynamic · Interactional · Contextual

1 Introduction

Computed Tomography (CT) is increasingly becoming part of the scope of practice for qualified radiographers. Indeed, in Australia, capability in CT is one of the primary capabilities required

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for a graduate to be registered with the Australian Health Practitioner Regulation Agency (AHPRA) (Australian Health Practitioner Regulation Agency 2016). As a result of this progression in scope of practice, CT has been included in undergraduate radiographer education for many years.

To explain the broad background of undergraduate education, it is necessary to understand some of the history behind its genesis. The era of schooling, as we know it today, arose largely from the industrial revolution. Prior to this, institutionalised education was limited to a few occupations, including medicine, law, military, and philosophy (Billett 2014). Most other occupations were learned by observing skilled tradesmen, or skilled practitioners. However, the boom in employment opportunities brought about by the industrial revolution and rapid advances in technology meant that opportunities to work with and learn from skilled workers became in demand, and substitutes had to be found. Thus, the first textbooks were written, as a substitute for actually learning from practice (Billett 2014).

Radiography has developed from a career learned on the job to being acknowledged as a profession requiring degree level education. In the process, it has transitioned from being learned almost solely in a hands-on environment, to being learned in a traditional tertiary education environment, with occasional forays into the clinical environment known as, among other titles, Workplace Learning (WPL) (Kilgour 2018). This has meant that undergraduate education in CT is largely theoretical, with practical training in the course of study limited to whatever opportunities students are given access to in their WPL placements.

It goes without saying that these opportunities in WPL are highly variable in quality of instruction, length of time allotted for training, and the amount of "hands-on" experience provided. Thus, when graduates enter the workplace for their first paid employment, although it is mandatory that they meet the professional capabilities as referred to above, their actual capability will be highly variable. In addition, a large part of their assimilation into the CT work environment will involve learning the specific protocols of the department they work in, and the operating systems and peculiarities of the particular brand of scanner installed in their workplace.

All of the above reveals that education in CT has two distinct phases: undergraduate education and postgraduate training. Of course, a radiographer can also choose to undertake formal postgraduate studies in CT, but the principles of these educational programs are similar to those employed in undergraduate education, only at a more advanced level. This chapter will examine postgraduate training in CT, and how to best develop the CT skills of qualified radiographers.

By way of introduction to this chapter, the various sub-areas of knowledge that are required to be a capable CT radiographer must be considered. These sub-areas are as follows:

1. CT theory—the principles of CT image capture and data manipulation.
2. Radiographic anatomy and pathology—particularly cross-sectional anatomy.
3. Equipment and instrumentation—variations between terminology and operating systems between the different vendors.
4. CT protocols—the scanning sequences, contrast rates, delay times, and image reconstruction sets required by the reporting radiologists, and how these vary or need to be modified for different presentations and suspected pathologies.
5. Physiology—particularly the use of intravenous contrast agents, their possible contraindications and side-effects, and what to do in the case of anaphylaxis.

Before considering each of the above aspects of CT education, it is important to describe some educational theories and principles. Once the attributes of these have been discussed, the most appropriate principles can be matched with the various sub-areas as described.

2 Andragogy: Adult Learning

Although first described in the literature in 1921, Knowles popularised the term andragogy in the 1960s. It was later defined as "…the art and science of helping adults learn" (Knowles 2015) (p. 61). Andragogy is a broad term, encompassing a multitude of different variations and activities that are designed to engage the adult learner and to help them absorb and retain the knowledge and skills that they are learning.

King (2017) describes four basic principles that are key to successful andragogy: learning must be self-directed; the learners' experiences must be used as a resource for learning; learning should grow out of the social tasks integral in adult life; learning must be applied immediately. When these principles are translated into actual educational practices, some of the learning techniques that are used are demonstrating respect to adult learners, engaging adult learners in active learning, incorporating their prior life experiences into learning, and applying the learning to their life needs.

These learning techniques, according to Blondy (2007), lead to three positive outcomes for adult learners. Firstly, use of andragogical principles cultivates lifelong learning in students. This is an essential attribute of a CT radiographer, as equipment and techniques continue to advance at a very great rate, and the radiographer needs to keep abreast of these rapid changes. Secondly, educational programs employing andragogical teaching and learning foster critical thinking in learners. Critical thinking is vital for a CT radiographer, as this is needed for functions such as designing scan protocols to best demonstrate particular conditions, analysing scanning errors to determine if they are due to machine or operator error, and many other aspects of the role. Thirdly, learning in the digital age requires becoming familiar with ever-changing technology, self-directed learning, and the flexibility of distance learning. The applications of these outcomes in educating CT radiographers are clear.

Some of the educational practices associated with andragogy will now be explored in the context of educating CT radiographers. One of the most prominent and universal principles of andragogy is self-directed learning (SDL). All will be familiar with the traditional teacher-controlled or teacher-centred model of learning. The teacher or instructor stands at the front of the classroom and relates the information that students are meant to learn. SDL turns this around so that the learner is in charge of their learning.

Because all adult learners approach their learning with different prior experience, levels of theoretical knowledge, and learning styles, SDL is suitable because it allows the adult learner to identify their learning needs, and prioritises the content, strategies, and resources which will best meet their personal needs (Brockett 1991). Thus, adult learners have to develop the ability to identify the strategies and resources, as well as the learning style, that best suits them.

One of the most prominent environments which exemplifies andragogical principles is workplace learning (WPL) (Candy 1991). The way in which self-directed learning is applied in CT education is a direct example of WPL. While a qualified and experienced CT radiographer will supervise the learner, they are generally doing so in a busy work environment with a full case-load. The supervising radiographer has certain expectations of the learner's prior knowledge, and if the learner does not meet these expectations, they have the responsibility to gain that knowledge in their own time.

When operating the CT scanner under supervision, the learner has the responsibility to ask for clarification of any aspect of the examination they don't understand. The learner is expected to identify the areas where they lack the required knowledge. Because the learner is an adult, and therefore has an expected level of maturity, the supervisor should be able to safely assume that the learner will not carry out any examination where they are not very certain they know exactly what to do.

Another way in which the WPL environment is ideal for the self-directed learner is that they can immediately apply their learning in the environment where they will be using this new knowledge (King 2017). Very few adults learn by just observation. When an adult learner can actively apply their learning within a very short time of having learned it, they are able to apply Gibbs Reflective Cycle (see Fig. 1) by testing, practising, and reinforcing what they have learned, and check up in a practical way their own understand-

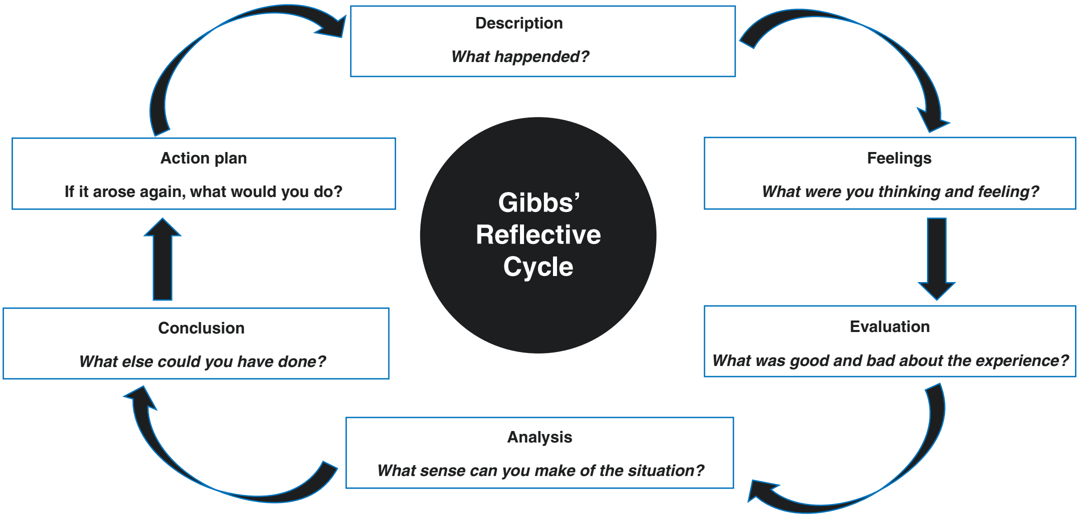

Fig. 1 Gibbs reflective cycle

ing of the new knowledge and skills (Begley 2007). A trainee CT radiographer will retain the new knowledge and its application by undertaking CT examinations under supervision as soon as possible.

The number of ways in which the principles of andragogy can be applied in CT education is beyond the scope of this chapter to discuss. However, one more merits inclusion: using the experiences of the adult learner as a learning resource in itself. Boud and Walker (1990) enlarge on how this concept connects adult learners to their learning, enhances their retention of knowledge, builds on their ability to apply that knowledge, and improves performance and productivity.

An experienced radiographer who is new to CT will have a history of dealing with patients in the radiological environment and also of radiographic anatomy. They will also undoubtedly have learned at least some CT theory in their undergraduate studies. These prior experiences can be drawn on in assimilating the new knowledge into their practice as a CT radiographer.

Gitterman (2004) describes the andragogical process of learning very well:

> *A primary teaching function is to structure the students' learning opportunities to interact with the subject and to personally experience its abstractions. Along the way, teachers point out the wonders, ambiguities, and inconsistencies of the content. (p. 100)*

The supervising CT radiographer is the guiding hand who advises the learner how to apply the theoretical content they already know in a real-world situation, and stands back as far as possible, allowing the learner to actually implement that knowledge. The author remembers his own experience when first learning CT. He had been a practising radiographer for 8 years at this stage, and the senior charged with his education in CT had a teaching style which consisted of "do this, press this button, then this one and that one", without letting the learner actually do it for himself. The learner became disheartened and wondered whether or not he had a learning disability, until a new supervising radiographer came on board and followed andragogical principles as outlined above. The difference it made was undeniable.

Adults generally learn more effectively if they know why the learning is important, if they can maintain responsibility for their own learning, if their life experiences are valued as part of the learning journey, and if they can learn in real-life situations rather than contrived or artificial ones (Mews 2020). Incorporating these principles into CT education is a win-win situation for all involved.

3 Pedagogy: Method and Practice of Teaching

In contrast to andragogy, pedagogy is more teacher centred than learner centred. It is a content model whose primary aim is to transmit information and employing that information in the development and application of skills. In a pedagogical teaching model, the teacher has preconceived ideas of the information and specific skills essential for transmission. They then arrange these into chapters or topics in sequence which seems orderly and logical to them, and decide on a method of passing this on to learners (Holmes and Abington-Cooper 2000).

At first, the concept of pedagogy as outlined above seems contradictory to the thoughts on andragogical learning and teaching already expressed in this chapter. However, if viewed correctly, pedagogy and andragogy can be seen to complement each other. What is required is the correct selection of pedagogy to allow andragogy to co-exist. Billett (2014) suggests that the best pedagogy for adult learners is "… learning in the circumstances of practice …" (p. 674). This will continue to be referred to as workplace learning (WPL).

How applicable then is the WPL paradigm as a pedagogy for radiographers learning CT? To explore this, we first need to look at the nature of CT practice. While there can be no argument that CT practice has a large technical element, it also is part of a healthcare profession. Therefore, by nature, it is also interactional, dynamic, and contextual (Kilgour 2018). It is possible to learn at least some technical skills in a traditional, didactic setting, but the interactional, dynamic, and contextual nature of any healthcare profession cannot be effectively learned in a classroom. Next, the nature of CT practice as outlined above will be unpacked.

3.1 Interactional Practice

In the course of a normal day, a CT radiographer will work cohesively with not only their patients and the patients' family and / or carers, but also a range of other healthcare practitioners. Healthcare provision is at its best when medical, nursing, allied health, and ancillary staff teams interact with the well-being of their patients at the centre of their interactions.

The literature enlarges on this, with published evidence that this kind of care centred around the patient enhances their recovery, and engenders ongoing health after recovery (Boudreau et al. 2007). A CT radiographer is responsible for managing complex equipment, determining imaging protocols, and communicating with patients, family / carers, and medical / nursing staff simultaneously (Björkman et al. 2013). All of this emphasises the interactions required of CT radiographers going about their daily business. CT practice steps this interactional complexity up to another level over projection radiography, as not only is the equipment more complex, but often the patients have more complex pathologies requiring more intervention from nursing / medical staff.

By working as part of a healthcare team, a CT radiographer can enhance their knowledge and capabilities in patient care by absorbing best practice from others in the team. This directly enhances the quality of care received by patients undergoing CT examination (Martin et al. 2005). When a patient trusts the CT radiographer, they are much more likely to cooperate. This cooperation is essential to achieving a diagnostic CT examination (Ehrlich 2009).

Not only do CT radiographers work in a multidisciplinary team, they also are part of an intraprofessional team. In a busy department, it is not uncommon to have one radiographer getting patients changed, cannulated, and positioned on the table, one scanning, and one doing image reconstruction and other associated tasks. This is part of the culture of the profession. Different professions have different standards and expectations, which reflect the collective beliefs, customs, behaviours, attitudes, professional language, and problem-solving methodology of that profession (Feuz 2014).

All of the interactions thus far described are part of the role of a CT radiographer and cannot be taught in a classroom. The WPL paradigm, however, allows a radiographer learning CT to be continually immersed in the interactions that are integral to the role.

3.2 Dynamic Practice

CT practice is never static and is always searching for what constitutes best practice. Aspects of CT practice which often exhibit change in themselves, or which encourage change, include technological advances, new developments in understanding and treatment of injury and pathology, and public educational programs leading to increased patient awareness. Practice is not only "fluid, dynamic and changeable", but is characterised by its "alterability, indeterminacy and particularity"(Boud 2009). Fortune et al. (2013) emphasise that health practitioner graduates must have "… capacity to manage contestable, unpredictable, and highly complex situations" (p. 32).

Progress in technology has more effect on the practice of radiography, including CT, than other less technology-dependent professions. CT scanning technology has progressed from just being able to produce axial scans of the brain, to a modality capable of imaging virtually any body system in any plane. Producing CT images on film which is difficult to archive, difficult to transmit and subject to deterioration, has been replaced by a fully digital environment which is faster, safer, and productive of a more permanent medical record (Okada and Blankstein 2009).

As a consequence of this dynamism in CT, WPL programs have had to adapt to this avalanche of new technology, in that radiographers learning the modality are, and need to be, exposed to these advances as part of their learning experience. However, the assessment of radiographers learning in this rapidly changing environment has not kept pace with these developments. In particular, the ability of radiographers to adapt to changes in the profession brought about by technological advances is not currently assessed. Clearly, the dynamic nature of the technology involved in CT must be incorporated into its assessment if the assessment is to be meaningful and authentic (Solomon 2007).

Progress in technology is a result of the nature of science—scientists are always exploring new and potentially better ways of achieving goals (Flick and Lederman 2004). This same overarching scientific principle of enquiry also applies to disease and injury and their treatments (Cohen 2012). Scientists are constantly making new discoveries about disease and its treatment, and this leads to new imaging techniques to diagnose and treat. There are countless examples of CT procedures being developed and refined for new diagnostic and interventional requirements. In order to be a professional practitioner in this rapidly developing field, radiographers must be assessed as to their ability to adapt and progress with the procedures they will be an integral part of as practising professionals. Clearly, WPL assessment in CT must be flexible and adaptable to accommodate such progress.

Because of this changing technological landscape, CT practitioners must be prepared to be dynamic in their adaptation to the changes. However, this dynamism is not restricted to adapting to technological change. Every situation practitioners come across require them to be dynamic in adapting their practice to the unique requirements of that situation. Professional practice requires practitioners to exercise reasoning, judgement, and decision-making in a dynamic environment (Govaerts et al. 2011). In order to facilitate learning in such a clinical environment, the CT learning process must be supervised and assessed, acknowledging that facilitation is in itself a dynamic process, where supervisors and students work together in an environment of mutual respect (Dickson et al. 2006).

As technology and knowledge of disease and injury have progressed, so has education for health science practitioners (Juanes and Ruisoto 2014). Even within postgraduate courses, there has been changed to accommodate evolving circumstances, with academic staff needing to keep current with rapidly evolving technology and procedures. However, this has not been reflected in concomitant changes in the way the performance of a radiographer learning CT is assessed (Kilgour 2011). Indeed, in many settings where radiographers learn CT, there is no formal assessment undertaken at all. Tertiary postgraduate CT education assesses theoretical knowledge, but cannot of itself assess the learner's actual capability, which incorporates adaptation to the dynamic nature of CT practice.

Practice is always transformative (Kemmis 2009), meaning that it produces changes in peoples' understanding, physical circumstances and social interactions. The ability of practitioners' actions to produce these changes is a reflection of how well their practice implements the dynamic nature of professional practice. In order for WPL assessment to capture this feature of learners' performance, the assessment process must be sufficiently broad and flexible to ensure that changes in practice are reported on and considered as part of their professional capabilities as a CT radiographer.

3.3 Contextual Practice

The practice of CT does not exist in isolation. On a micro level, it exists as part of the radiology department, and the CT radiographer is an integral part of the overall team of radiographers. On a macro level, the CT radiographer, particularly in a hospital environment, is a part of several different healthcare teams. For example, in the case of trauma, the medical team responsible for the management of the patient depends on the CT radiographer to provide not only a diagnosis, but also detail of any injuries sustained. An oncology team is dependent on the CT radiographer for staging of the patient's malignancy. Mobile CT units are increasingly being utilised in orthopaedic and neurological surgery.

All of the above examples are different contexts for CT practice. CT practice is influenced by so many factors outside of the core profession specific skills, and the context of the assessed performance must always be taken into consideration. The way skills are practised depends on existing resources, the time available to exercise the skill, the nature of the patients for whom the skill is practised, the culture of the workplace in which it is carried out and the ability of the practitioner who is carrying out the task (Trede 2015). Therefore, determining learners' capability to undertake CT practice must take these contextual factors into account in order to be a reflection of their actual capability.

Whether the exercise of skills should be classified as an achievement depends very much on the context of the situation in which it was exercised (Sadler 2010). A fundamental aspect of the efficient and capable performance of professional activities relates to situational understanding, which involves taking the context of the performance into account. Because of the variations in the contexts of clinical performance, no single assessment method can evaluate the entirety of a student's professional capabilities (Hager et al. 1994).

CT radiographers' performance in the workplace is moulded by a variety of external factors, including the context of the situation, as well as the interactional, social, and dynamic features of professional practice already discussed. Therefore, the assessment of CT workplace performance should be based on their practice capability, rather than theoretical achievement (Trede and Smith 2014). The skills that radiographers develop in handling these external factors in real practice contexts create confidence for them to work in other contexts which are previously unencountered (Walsh 2007). The situations into which a radiographer learning CT is placed in order to develop these skills should be deliberately designed to promote transferability from one context to another (Orrell et al. 2010). This argument emphasises a vital feature of CT practice, that is, practitioners must be able to undertake their practice irrespective of the context of their practice. They must be able to adapt to whatever circumstances are present and remain competent and capable.

When these general principles are followed in planning and implementing the program that a radiographer learning CT undergoes, learners are enabled to encounter a wide variety of contexts. Therefore, due to the wide variety of contexts which learners experience in such programs, adopting traditional assessment methods will result in questionable credibility of the assessments produced. These traditional methods attempt to apply the scientific, psychometric assessment processes used in traditional education to the constantly changing context of CT practice. The world of CT practice requires a different assessment paradigm to that of theoretical, on-campus academic assessment of learning (Coll and Zegwaard 2011). This paradigm is not so much about measurement, as it is about reasoning, judgement, and decision-making in the variety of contexts encountered (Govaerts et al. 2011).

4 Assessment of the Learning CT Radiographer

As has been previously stated, in many departments where radiographers are trained in CT practice, there is no formalised assessment of their achievements, which means that there is no measurable way to determine whether or not they are ready to practice independently. In a hospital setting at least, a CT radiographer often has to work independently of other radiographers. This is often the case when on call or working a midnight to dawn shift. These situations are anecdotally when the most challenging and complex patient presentations occur, and the radiographer must adapt to these presentations. Whilst the technical aspects of CT practice are vital, they are more easily learned than is the ability to adapt to the interactional, dynamic, and contextual nature of practice. Therefore, before a radiographer is determined to be ready for independent practice in CT, a formalised assessment should be undertaken. Before the nature of this assessment can be determined, the question must be asked, “What is actually to be assessed?”

4.1 Competence and Capability

The pertinent literature often uses the terms “competence” and “capability” interchangeably (Kilgour 2018), therefore it should not be unexpected that practitioners often do not understand the difference between the two terms. However, Fraser and Greeenhalgh (2001) provide clarification, defining competence as “…what individuals know or are able to do in terms of knowledge, skills, attitude”, and capability as the “…extent to which individuals can adapt to change, generate new knowledge, and continue to improve their performance” (p. 799). These definitions make it clear that whilst assessing the technical prowess of a CT radiographer can determine their competence, a determination of competence cannot measure their actual capability in CT practice.

In the light of what has been discussed thus far, a model of capability in CT practice is proposed below (Fig. 2):

No radiographer or radiography educator would argue that technical competence is unimportant, however, this model shows competence to be a subset of capability. Therefore, in order to assess a CT radiographer’s readiness for indepen-

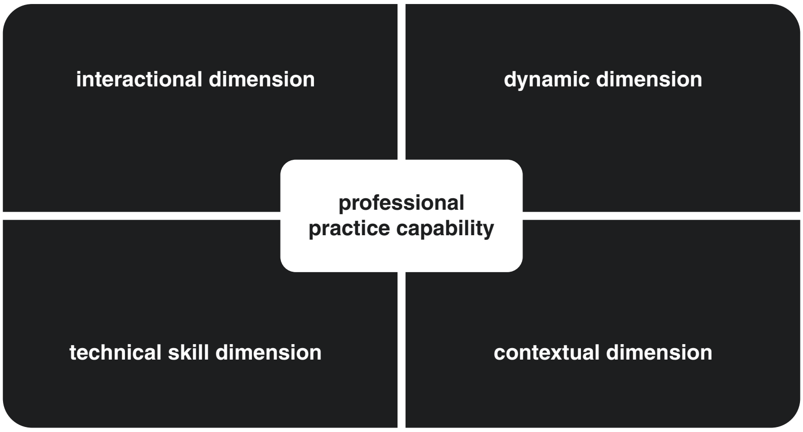

Fig. 2 Model of capability in CT practice (Kilgour 2018).

dent practice, an assessment of capability incorporates an assessment of competence by default. Assessing capability is a far more reliable method for determining readiness to practice as a CT radiographer than simply assessing competence, as it determines the ability of the practitioner to accommodate not only the inherent technical complexities, but also their ability to adapt to changes, use problem-solving skills to find solutions to problems they have never before been confronted with, and interact as part of the healthcare team, regardless of circumstances.

4.2 Assessment for Learning and Assessment of Learning

One widely accepted educational principle is that assessment drives learning (Dijkstra et al. 2010). According to this principle, when capability in professional practice is assessed as an integral part of CT radiographer education, skill in professional practice will be enhanced.

It can also be argued that assessment drives behaviour, in that students exhibit the behaviours they believe will allow them to pass assessment tasks, without necessarily obtaining the deep learning and understanding that develops the characteristics of a professional practitioner. Tennant et al. (2009) reflect that the tension between assessment for certification and assessment for learning traditionally has led educators to set assessment tasks that promote assessment of learning, rather than making their assessment a learning process in itself. They assert that the type of quality assessment which motivates students to engage with the task, and use it to learn for their future practice, needs to foster deep learning that can only be facilitated during WPL by dialogue, reflection, and collaborative learning in the clinical environment.

Either way, incorporating assessment of professional practice capability into assessment of CT radiography performance will in time facilitate the dissemination of understanding the nature of professional practice throughout the profession. The recognition in the healthcare community of radiography as a profession will be enhanced as the principles of professional practice are inculcated in future practitioners.

The question must now be asked as to the most effective way to assess CT capability.

4.3 Professional Judgement

Although at face value professional judgement may seem subjective, by necessity it plays an essential role in the assessment of practice capability and is no less reliable than so-called objective assessment (Hager et al. 1994). It typically has a high degree of credibility, dependability, confirmability, and transferability, and its validity is assured because a sample observation of a learner's practice is the most direct basis for making a judgement about professional capability (Hager et al. 1994). Clinical assessors can almost universally identify good performance when they see it, but if one was to ask an experienced assessor exactly what they are looking for to classify performance as capable, they may have a deal of difficulty doing so (Sadler 1989). Sadler (2009) refers to the concept of holistic grading, where the primary influence is the supervisor's emerging global judgement of the learner's performance. Of course, this judgement must be referenced to accepted standards for the relevant profession.

Contemporary assessment literature (Boud and Dochy 2010; Sadler 2005) often refers to the role of standards in assessment. However, using pre-determined professional capability standards as the measure for assessment of professional capability does not prescribe that professionals' actions should be the same as the next person in a given situation. Application of these standards should allow for professional discretion (Feuz 2014). When assessing capability, the context of the performance needs to be integrated into the considerations (Johnsson and Boud 2010). Therefore, assessing capability of a CT radiographer is not really a process of measurement, but rather the application of judgement, reasoning, and decision-making in a dynamic environment (Govaerts et al. 2011). This is a qualitative process.

It is not constructive to try and force professional qualitative judgements into some type of artificial quantitative format. We should recognise and value these judgements for what they are—an accurate, professional reflection of learners' practice capability.

Professional judgement of clinical assessors provides not only the most meaningful information regarding practice capability, but also a superior approach to assessment methods commonly thought to be objective. At least one assessment component of the assessment framework developed should be based on the professional judgement of experienced supervising CT radiographers.

From the discussion above the following propositions can be drawn:

1. An assessment framework for CT practice should allow supervisors to exercise their professional judgement in assessing practice capability of radiographers learning CT.
2. Technical competence should be assessed, but this is just one part of the skillset that affords practice capability.
3. A CT assessment framework should include actions that facilitate and enhance student learning, not just assessments that measure it. One proven method for attaining this is to use a reflective portfolio (Pinsky and Fryer-Edwards 2004).
4. There should be more than one method of assessment of CT practice capability contributing to the developed assessment framework.

It should also be pointed out that assessment of CT practice capability needs to align with professional and accreditation body standards.

4.4 Application to Assessment of CT Capability

Many different models of assessment exist, and for assessment to be credible and transparent, the models employed need to have a good match with the purpose of what is being assessed. Psychometric measurement models are suitable to assess technical domains but they are not sufficient to credibly assess for student capability which should include interactional, dynamic, and contextual features. Yet current models for assessment of performance for radiographers learning CT are largely psychometric (Kilgour 2011). The professional judgement of experienced practitioners has been shown to be trustworthy in determining the capability of learners they are assessing (Yorke 2011), and yet in current assessment models, this is largely ignored.

The past focus on assessment of technical skills has meant that clinical CT supervisors feel under-equipped to assess learners' broader professional skills. They either use their own ideas of what constitutes good performance, without reference to standards or assessment criteria, or write an incomplete report, feeling that this makes them less likely to be "wrong" (Burchell et al. 1999). The result is a superficial approach to WPL-based assessment in the radiography profession in general, and CT in particular (Kilgour et al. 2014), with a focus on what is measurable and visible.

This superficial approach to assessing professional skills is reflected in the assessment strategies employed by supervising CT radiographers, if indeed any formal assessment is carried out. These typically report rigorously on technical skills, and when other skills are included in assessment, the assessment strategy is psychometrically based. Psychometric assessment strategies are broadly suitable for assessing technical competence—in that many highly technical skills are either "can do" or "can't do" (Yorke 2011). However, such an approach is not sufficient for assessment of more complex professional practice capability such as is required in CT. From the point of view that capability is not the sum of separate entities but an integrated whole, it is only logical to conclude that no single instrument, no matter how psychometrically sound, can provide all the information for a comprehensive evaluation of competence in a health-related domain (Dijkstra et al. 2010). Different aspects of capability therefore require different assessment strategies.

Whilst it is not in the scope of this chapter to propose a specific assessment model for CT capability, the literature as discussed demonstrates that the technical skills required of a CT radiographer can be assessed by a psychometric or scientific (quantitative) scale, but that the other aspects of professional practice in CT need to be assessed by qualitative means, such as a narrative comparing learner performance to professional standards, and targeted reflective portfolios kept by learners.

5 Conclusion

As radiographers learning CT are invariably adult learners, the principles of andragogy as set out in this chapter are clearly applicable, suggesting that a self-directed learning program, acknowledging the learner's prior experiences and knowledge as part of the learning, will be efficacious in maximising the learning and resulting capability of those involved.

This chapter also highlights the importance of hands-on, contextual learning, rather than a focus on theoretical knowledge, in developing CT practice capability.

Current practice in CT capability assessment remains fragmented and heavily psychometric based with a focus on assessing technical skills, and little consideration given to either the professional judgement of learners' supervisors, or the interactional, dynamic, and contextual dimensions of clinical practice that together with the technical skill dimension make up professional practice capability. The concepts of education and assessment presented in this chapter are informed by theoretical ideas of professional practice and how such practice capability can be learned. Drawing on the theories and research findings discussed above will require a cultural shift for CT assessment practices because it would mean embracing the interactional, dynamic, and contextual dimensions of practice that together with technical skills make a capable CT radiographer. Past evidence demonstrates that radiography as a profession, while quick to accept changes in technology, is slow to accept changes in education and its assessment.

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