ANALYSIS OF OCCUPATIONAL AND PATIENT EXPOSURE TO RADIATION WITHIN NEWFOUNDLAND AND LABRADOR DIAGNOSTIC IMAGING DEPARTMENTS

by

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Abstract

Medical imaging modalities that use ionizing radiation have seen an increased use in modern day medicine. Not only have these procedures allowed us to see the unseeable, but technology advances, an ever-growing patient pool, time-saving ability, and cost reduction strategies have assisted in the popularization of medical imaging modalities. Despite their profound benefits, the potential risks posed by ionizing radiation cannot be overlooked. This thesis investigates radiation exposure within two unique disciplines of medical imaging: patient populations undergoing computed tomography (CT) scans and health care professionals engaged in interventional fluoroscopy procedures.

The patient-focused study examines variations in cumulative procedural dose among individuals undergoing CT scans of the same anatomical region. By comparing dose levels within and between medical imaging departments in Newfoundland and Labrador, this study identifies potential differences in scan protocols, highlighting areas for protocol optimization and standardization. Results from this study underscore the need for further investigation and the development of strategies aimed at reducing dose variation across provincial medical imaging departments.

The second study focuses on radiation exposure to health care professionals involved with interventional fluoroscopy procedures. In conjunction with Eastern Health's pre-existing dose monitoring tools (dosimetry), the study aims to provide an additional perspective for dose monitoring that will help departments align with the provincial radiation health and safety regulations under the Radiation Health and Safety Act set for occupational radiation exposure. We will examine the hypothesis that patient dose estimates are directly correlated with staff exposure. An obvious correlation can serve to identify causal events in the case where a

dosimeter badge has recorded an unusual exposure, help provide more timely feedback to staff regarding their potential exposure, and provide information that may be used to proactively manage staff exposures. The study aims to provide a mechanism for greater protection to health care professionals who are at risk from elevated levels of radiation exposure.

Through these complementary studies, this thesis highlights the importance of further investigation and the development of targeted strategies to address dose variation across provincial medical imaging departments. The findings serve as a foundation for future initiatives aimed at optimizing scan protocols and enhancing radiation safety measures for both patients and healthcare professionals.

General Summary

Diagnostic imaging is a powerful and widely used healthcare tool. The specific modalities using x-radiation, projection radiology and cross-sectional computed tomography (CT), are easily the most frequently used imaging modalities. CT imaging collects quite a bit more data than projection radiology (e.g. a chest x-ray), as a result CT normally imparts a greater dose to the patient. CT protocols should be optimized to provide diagnostic image quality at the lowest possible dose. This investigation examined the average dose imparted for 12 common CT protocols at six sites and noted significant variation by site.

Staff receive small doses of radiation from rays scattered by the patient. This is most likely to happen in fluoroscopy/angiography procedures because a) the exposure time is relatively long and b) the staff must be in the room when the beam is active. The best way to minimize doses from scattered radiation is to ensure efficient protocols and adherence to safety procedures. At present staff dose is reported quarterly and this dose not lend itself well to process improvements. This investigation aimed to determine if Refrence Point Dose could be used as a proxy for or to augment existing dosimetry methods.

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List of Abbreviations

AEC	Automatic exposure control
ALARA	As low as reasonably achievable
APC-	Abdomen pelvis without contrast
APC+	Abdomen pelvis with contrast
CAPC-	Chest abdomen pelvis without contrast
CAPC+	Chest abdomen pelvis with contrast
CC-	Chest without contrast
CC+	Chest with contrast
CT	Computed tomography
CTDIvol	Computed tomography dose index-volume
DAP	Dose area product
DIR	Dose index registry
DLP	Dose length product
DNA	deoxyribonucleic acid
DRLs	Diagnostic reference levels
Gy	Gray
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
INWORKS	The International Nuclear Workers Study
L Spine	Lumbar spine
LDRL	Local reference levels
LDS	Landauer Dosimetry Service
LLS	Life Span Study
LNT	Linear non-threshold
LQ	Linear-quadratic
mA	Milliamperes
mGy	Milligray
mSv	Millisievert
NDS	National Dosimetry Service

NSWS	Nuclear Shipyard Worker Study
PA	Pulmonary angiogram
PET	Positron emission tomography
RCOL	Renal colic
RHC-	Routine head without contrast
RHC+	Routine head with contrast
RHCC	Routine head with/without contrast
RPD	Refrence point dose
SID	Source to image receptor distance
SNR	Signal to noise ratio
SPECT	Single-photon emission computerized tomography
Sv	Sievert
ED	Effective dose

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Chapter 1 Introduction

1.1 Overview

Diagnostic Imaging is a branch of medicine highly utilized in modern day clinical settings. It is most known for its use to diagnose disease and injury. Before the growth of such interventions, highly invasive procedures were the only possibility for the treatment and diagnosis of certain disease and illness. The first ever x-ray image did not depict a broken bone or a condition of the lung, but rather the hand of Wilhelm Röntgen's wife, on her finger, a large dark wedding ring. Since the production of the first radiograph in 1895, diagnostic imaging has radically evolved. Diagnostic imaging now includes such modalities as magnetic resonance imaging, ultrasound imaging, general x-ray, CT scans, positron emission tomography (PET), nuclear medicine (NM), fluoroscopy, angiography, and mammography to name a few. This report will focus on procedures that involve ionizing radiation. Ionizing radiation carries sufficient energy to break molecular bonds. When these broken bonds alter the structure of deoxyribonucleic acid (DNA), the consequences may be cell death or mutation.

Technological advances in the way in which ionizing radiation is utilized, and an ever-growing patient pool availing of such procedures, bring both risks and benefits to an individual's health. The 2019-2020 Canadian Medical Imaging Inventory report computed projections on the future number of medical imaging exams to be performed within provincial jurisdictions [1]. Projections were calculated as the products of per capita exams performed in 2020 and the population projections in 2025, 2030, 2035, and 2040 (retrieved from Statistics Canada 2016 Census [2]). Provincial and Territorial validators provided the number of imaging exams performed in 2020. Separate computations for CT and PET-CT, and a combined computation for SPECT and SPECT-CT showed a significant increase in the volume of exams anticipated to be

performed by 2040 [1]. The report indicated that by 2040, CT exams being performed in the Canadian health care system are expected to increase by 18%, PET-CT exams by 16%, and SPECT and SPECT-CT exams combined will increase by 13% [1]. These statistics clearly show ionizing radiation imaging modality growth. Comparable trends are recorded in health care facilities globally [3] [4] [5]. In the United States, investigators found seven integrated health care systems that experienced a significant increase in CT imaging from 2000 through 2016 [6].

To protect staff performing higher volumes of procedures using ionizing radiation, agencies have set occupational ionizing-radiation exposure limits. Doses that exceed the recommended provincial limits of 50 mSv as the annual permissible whole body occupational dose limit, and 750 mSv as the annual extremities dose limits for radiation workers [7] may have the potential to cause adverse biological effects. Such limits are in line with the International Commission on Radiological Protection (ICRP), the International Atomic Energy Agency (IAEA), and the Canadian Federal Provincial Territorial Radiation Protection Committee. Recent speculation has also proposed that low-dose or multiple low-dose exposures (<100 mSv) may produce either positive or negative health outcomes [8].

In addition to ICRP's three Fundamental Principles of Radiological Protection (justification, optimization of protection, and dose limitation) [9], health agencies have adopted the "As Low as Reasonably Achievable" (ALARA) principle to avoid radiation exposures that have no direct benefit. The ALARA principle also applies to patients exposed to ionizing radiation for medical benefit. Unlike staff, there are no radiation dose limits set for patients. Any exposure to a patient must be justifiable and necessary for a specific clinical purpose. During any exposure, patients receive a dose of ionizing radiation, putting them at risk for the same adverse biological effects that may be experienced by exposed staff and operators. Operators of ionizing radiation

equipment are required to adhere to guidelines (i.e., protocol optimization, radiation protection training, and equipment calibration) that help prevent radiation over exposure to the patient population.

Medical imaging procedures that utilize ionizing radiation can be ranked for the risk associated with occupational radiation exposure. Some procedures, such as simple chest x-rays, carry little risk to the operator. On the other hand, fluoroscopy exams often require a team, including radiologists, technologists, and nurses to be present in the room when the x-ray beam is active. Fluoroscopy acquires real-time x-ray images to assist in guiding a medical apparatus through the body. It includes procedures such as angiography, angioplasty, and treatment of lower limb and abdominal aortic aneurysms. Health care professionals performing such procedures, and any personnel in the procedure room, will be exposed to low doses of ionizing radiation scattered from the patient. It can be argued that these doses are very low and not a concern. However, a high frequency of exposure to low dose radiation, also known as lifetime dose, may have some relevance to developing stochastic effects [8].

Four areas of concern to interventionists and staff are: the whole body exposure (calculated as effective dose) and the exposure to the eyes, skin, and extremities (measured as equivalent dose) [10]. Standards and protection policies have been adopted in the province of Newfoundland and Labrador to limit occupational exposure [7]. The policies require the safe operation of equipment, the use of personal protective equipment (lead aprons and shields), and passive dose monitoring (badge dosimetry).

Although fluoroscopy may be the greatest source for staff dose, it is not for patients. The largest contributor to patient radiation dose is CT [11]. Organ dose during a scan can be 100 times

higher than the dose imparted in a chest x-ray [11]. Project 2 in this thesis will examine dose variation in CT exams. CT protocols are designed (factors include: kVp, mAs, scan length, overlap, filters, reconstruction parameters) and performed by anatomical site (e.g., head, neck, chest, abdomen, pelvis, and legs). Each anatomical region has an associated scan protocol, and the patient dose depends on the chosen protocol. Theoretically, the doses prescribed by different protocols should not significantly vary. However, routine monitoring reports have shown this is not always the case. This raises a concern that the scan protocol is not optimized to ensure optimal exposure taking into account diagnostic quality and patient safety.

This study has multiple aims: 1. To provide an additional dose monitoring tool for health care professionals involved in interventional fluoroscopy by investigating the potential correlation between patient dose and staff dose. To our knowledge, such a correlation has not yet been tested in a clinical setting, but with recent advancements in the ability to predict patient exposure, such a study is feasible. If a clear association between patient and staff dose is found, the data will be used to identify causal events in the case where a dosimeter badge has recorded unusual exposure during the quarter, provide more timely feedback to staff regarding their potential exposure, and provide information that may be used to manage staff exposure proactively. 2. To investigate the observed variation between patient dose for identical CT examinations and variation in procedural dose between and within local medical imaging sites. If factors can be identified for the cause of this variation, recommendations may be developed to ensure patients are receiving only the necessary dose of radiation. The ultimate goal is to provide a basis to reduce the variation in patient dose and to minimize cumulative procedural staff dose.

1.2 Radiation Biology

X-ray radiation was implemented in medical centers soon after its discovery in 1895. Its ability to see the unseeable was immediately noticed for its benefit in diagnosing disease and illness. Many events throughout history proved ionizing radiation's ability to cause adverse side effects. Early experimentation of radioactive materials and unregulated x-ray imaging that took place after its discovery demonstrated such adverse biological effects. The field of radiation biology can help describe the changes that occur on a cellular level following the absorption of ionizing radiation. Cellular responses are complex; cell cycle, cell type, and radiation dose interact to produce a variety of biological responses [12]. Ionizing radiation may transform normal cells into cancer cells or trigger apoptotic or necrotic processes. The biological effects caused by ionizing radiation can be defined as either stochastic effects or tissue reactions (previously called deterministic effects). These effects can be non-somatic (hereditary damage) or somatic (non-hereditary damage).

Early use of x-ray radiation overlapped with a lack of understanding regarding the dangers of ionizing radiation on health. Reports of erythema, dermatitis, alopecia, and skin cancer were observed by early x-ray operators and their patients [12]. Only after observing adverse effects did research postulate how ionizing radiation interacts with matter. Population and animal studies determined that ionizing radiation could have long-term and short-term biological effects. A 1902 publication titled *The Roentgen Rays in Medicine and Surgery* served as an instruction manual and informative text on the use of x-ray radiation in the diagnosis and treatment of disease at the Boston City Hospital. During this period, it had already been determined that ionizing radiation can cause significant burns if the proper precautions are not practiced. The long-term biological effects of ionizing radiation still, however, remained somewhat of a

mystery. The text states, “Harmlessness of X-Ray Examinations if Proper Precautions are Taken- The fact that several thousand of X-rays examinations have been made at the Boston City Hospital alone, and always without unpleasant results following, demonstrates the entire harmlessness of these examinations when carried out with proper care” [13]. The “precautions" to be taken were indeed vague in comparison to modern day standards. Early experimenters, including Marie Curie, Clarence Madison Dally, William J. Morton, and Nikola Tesla, reported some level of radiation sickness upon working closely with x-rays and radioactive substances [14]. An increase in accounts of acute injuries, leukemia, and aplastic anemia in the radiation worker population during WWI, atomic bomb survivors of Hiroshima and Nagasaki, as well as the “Radium Girl" watch painters [14] proved ionizing radiation’s biological hazards had the potential to conceal themselves but were not to be dismissed.

The effects of radiation are dependent, to some degree, on various properties. These properties include the absorbed dose (quantity), length of exposure (dose rate), and the type and energy (quality) of the radiation [12]. The radiation exposed area should also be factored into the equation as different cell types experience different levels of radiosensitivity. The cell-cycle exhibits different levels of radiosensitivity. Rubin and Casarett described these relative sensitivities in their highly accepted report [15]. In summary, cells that fall within the genera of high radiosensitivity fit the profile of having high division rates, high metabolic rates, and are non-specialized (non-differentiated). Typically, well-differentiated cells with low division rates are relatively insensitive to ionizing radiation. Rubin and Casarett separated tissue types into five classes, ranging from high relative radiosensitivity to low relative radiosensitivity (Table 1).

Table 1.1 *Tissues in decreasing order of relative radiosensitivity based on relatively direct tissue effect (hypoplasia)*

Relative radiosensitivity	Tissues
High	Lymphoid, bone marrow, testes, ovaries, intestines
Fairly high	Skin, epithelial lining of organs (bladder, esophagus, optic lenes, gastrointestinal tract, urinary tract)
Medium	Connective tissue and nervous tissue (growing bone tissue, growing cartilage, fine vasculature)
Fairly low	Mature cartilage and bone, salivary glands, respiratory organs, kidneys, liver, pancreas, thyroid, adrenal and pituitary gland.
Low	Muscle and neuronal reissue (brain and spinal cord)

A relationship exists between the absorbed dose and radiation-induced health effects. Absorbed dose is a measure of the energy deposited within a given tissue mass from a radiation source. Exposure to very high levels of radiation correlates with an increased risk of both acute and long-term health effects [16]. Low radiation levels like doses absorbed from environmental sources are unlikely to cause any immediate health effects, but play a minor role in overall cancer risk [16]. Any radiation dose, big or small, has the potential to inflict biological effects; however, there are more immediate risks associated with a higher absorbed dose. The dose rate additionally influences health effects. An individual that receives a dose in increments over an extended period will encounter fewer major health effects than if the same dose was received all at once [17]. There are two types of ionizing radiation, particulate and electromagnetic. X-rays and gamma rays are massless electromagnetic radiation while alpha and beta particles are particulate radiation with measurable mass. Alpha and beta particles have relatively low penetrating power, while gamma rays and x-rays have high penetrability [18]. Regardless of

radiation type, a radiation exposure can be achieved in different ways (e.g. a low absorbed dose over a very long period or a high absorbed dose over a short period).

Tissue reactions are a consequence of being exposed to a threshold dose. The severity of the effect will increase linearly with dose above the threshold [19]. Tissue reactions are certain to occur if the dose meets threshold. Tissue reactions include erythema (skin irritation), cataracts, sterility, and hair loss. Stochastic effects occur by chance, potentially without a threshold [19]. In some models, as the dose increases, the probability of experiencing a stochastic effect increases. Dose may not correlate with the severity of the effect. These stochastic effects include cancer and potentially hereditary effects.

Mechanistically, two pathways may produce cellular injury. The direct path occurs when the incoming photon damages critical cellular molecules such as DNA. The indirect path occurs when the incoming photon interacts with a non-critical molecule, such as water, forms a free radical, and the free radical damages critical cellular molecules. X-rays are sparsely ionizing. They are more likely to cause injury via free radical mediated pathways. For example, the products of water ionization are the hydronium atoms and the hydroxyl radical. The hydroxyl radical is highly reactive. It may diffuse to the DNA and initiate a chain of radical formation. Most injuries will be sub-lethal, meaning they may impair cell function. Some damage will be severe enough to impair cellular reproduction, possibly leading to cellular death via apoptotic or necrotic pathways. Rarely, the injury will result in the loss of cell cycle regulation and or cell line differentiation. These events may lead to cancer and, in theory, to hereditary effects in germ cells.

Some healthcare workers' occupational tasks include exposure to low-dose radiation. The threshold at which deterministic effects occur is not commonly reached during interventional

procedures where prolonged low doses are experienced. It is still unclear whether prolonged low-dose exposure puts medical radiation workers at risk for adverse stochastic effects. There are very few epidemiological studies evaluating the effects of low-dose exposure. Most studies, such as the Life Span Study (LSS) [20], follows the effects on populations exposed to high doses of radiation. The International Nuclear Workers study (INWORKS) followed radiation workers employed in France, the UK, and the USA who experienced low dose protracted or intermittent radiation exposure [21]. Results showed a positive association between prolonged low-dose radiation exposure and leukemia mortality. The study population experienced a mean annual dose of 1.1 mGy (SD 2.6) while employed as radiation workers [21]. An assessment of 26 epidemiological studies examining low-dose ionizing radiation and cancer risk concluded that a large body of research supports an association between increased cancer risk from low-dose ionizing radiation [22]. Some academics argue it is difficult to quantify the risk associated with low-dose radiation exposure because of the limited evidence supporting a positive association. The Nuclear Shipyard Worker Study (NSWS) examined if shipyard workers who worked in radiation areas experienced an increased risk of leukemia or other cancers [23]. Workers with prolonged exposure to low levels of gamma radiation were compared to workers performing similar duties in radiation free locations. Compared to the general population, the nuclear workers did not experience an increased risk of any cancer except for mesothelioma, which was likely caused by asbestos exposure and not exposure to low-dose radiation [23].

A stochastic effect that has been more clearly observed within interventional cardiologist and interventional radiologist populations is the risk of cataracts [24]. Radiation-induced cataracts result from radiation damage to dividing cells located within the eye's lens. It was previously thought that radiation-induced cataracts required a higher dose to develop. Recent investigations

of atomic bomb survivors, radiologic technologists, radiation therapy patients, and Chernobyl clean-up workers show that radiation-induced cataracts can occur from doses much lower than the initial predicted threshold dose [24]. These findings have encouraged lens dose evaluation and medical staff to wear leaded protective eyewear.

Although millions of patients have had CT studies, there is no clear association between the dose received and stochastic risk. CT is considered one of the highest radiation-dose imaging modalities, so if an association existed, it might be expected from this source. The effective doses from standard CT procedures generally fall within the range of 1 to 10 mSv [25]. This dose is not prolonged, like those experienced by occupational workers, but rather an episodic dose acquired in a few seconds. Although still considered a low-dose, this level of exposure has been speculated to marginally increase an individual's risk of radiation-related cancer mortality later in life. This speculation is based on observations of a population of Japanese atomic bomb survivors who received doses of 5 to 20 mSv [25].

The potential health consequences from radiation cannot be ignored in health care workers routinely exposed to low-dose radiation or patients receiving episodic low-doses for a given CT examination. To ensure minimal harmful effects from ionizing radiation, applied safety policies and programs follow the most conservative approach. Continued research may also help to clarify the relationship between prolonged low dose exposure and significant biological effects.

1.3 Dose-Dependent Models

Several models have been proposed to help quantitatively characterize the relationship between radiation dose and its relative risk to humans. The linear non-threshold (LNT), linear-quadratic (LQ), linear-threshold, hormesis, and non-linear threshold models have been widely reported

[26] [27]. These models help build the framework for radiation protection strategies. The LNT model is currently used to guide all modern radiation protection strategies [30]. There is, however, a debate about whether the LNT model is the most appropriate model for such strategies [28] [29].

The LNT model presents dose-response as a positive linear function starting at the origin [26]. This model is used to estimate stochastic health effects resulting from ionizing radiation. The dose-response relationship described by this model is based on the probability of the effect occurring (stochastic), rather than its severity. The relationship is linear in the sense that as dose increases so too does the probability of cancer occurrence. Another characteristic of this model is that it does not apply a threshold dose; even the low dose typical in interventional procedures can, in theory, result in a stochastic effect. Many questions have been raised regarding the accuracy of this model, specifically whether there is evidence supporting the no-threshold characteristic- a characteristic deemed difficult to prove [28]. The LNT model is currently the most conservative model and is used to develop all occupational and patient radiation safety standards, including dose limits for workers and members of the public [30].

Similar to the LNT model, the linear-threshold model suggests a linear dose-response relationship. The linear-threshold model reports greater observable risk at higher doses and lower observable risk at lower doses. This model differs from LNT in its threshold. Health risks require a higher dose to present any clinical effect, and below the threshold value this effect will not present. There is also a non-linear threshold model where the response severity changes along the dose curve. This model is also referred to as quadratic or sigmoidal and is used to estimate tissue reactions.

Linear-quadratic (LQ) and hormesis models hypothesize two distinct dose-response relationships. The hormesis model states that low doses of ionizing radiation may, in theory, be protective [26]. It is proposed that low doses of radiation stimulate cell repair mechanisms. The stimulation of these repair mechanisms has a beneficial outcome for future incidences reducing their potential to cause severe damage. The LQ model suggests at lower doses of radiation the dose-response relationship is linear, while higher doses the relationship is quadratic [26]. Considerable debate exists in the literature about which among these models is more appropriate and if any are most appropriate.

1.4 Occupational Radiation Standards and Regulations

In Newfoundland and Labrador, the health and safety of personnel exposed to occupational ionizing radiation is guided by the Radiation Health and Safety Act set by the provincial government [31] [7]. The supporting regulations are in line with the International Atomic Energy Association's operational guidelines. The 2021 Report on Occupational Radiation Exposure in Canada estimates the total population of registered radiation workers to be 170,000 in 2018 [32]. The national dose registry acquires and analyzes data for many occupations, including individuals employed in nuclear power plants, uranium mines, dental offices, and hospitals [32]. Over half (58%) of the national registry are workers from the medical sector, reporting a mean effective annual dose of 0.08 mSv. A provincial breakdown indicated 2,282 radiation workers were employed within the province of Newfoundland and Labrador, 1,758 of whom worked within the medical sector. Provincial radiation workers from the medical industry received a mean effective annual dose of 0.06 mSv, a dose lower than the observed national value.

All workplaces within the province that use ionizing radiation in practice must be licensed to do so. All license holders, by law, are required to implement a radiation protection program for the safety of all workers. All programs must include the following procedures to ensure radiation exposures comply with ALARA principle [7].

- Instructions covering the safe operation of radiation equipment.
- Instructions covering radiation protective procedures.
- The use of protective equipment.
- Procedures to be followed in case of an emergency.

Supplementary information is provided to all radiation workers regarding the risks to developing embryos that may arise during pregnancy.

As for the program requirements, standardized radiation monitoring tools must be used to detect radiation exposure to all employees. The whole-body dosimeter (badge) is the standard for occupational radiation monitoring. It is worn on the front of a worker underneath any personal shielding. During fluoroscopy procedures, another dosimeter is often placed on the collar under the lead apron (if used), on eyeglasses, and/or finger or wrist. This will allow for the monitoring of exposure to the thyroid, the eye's lens, and the interventionist's hand. The management and assessment of data must also be implemented with the use of dose-monitoring tools. The National Dose Registry contains the dose records of Newfoundland radiation workers who volunteer for their occupational doses to be recorded. The National Dose Registry can provide workers with a dose history summary report upon request. The Registry also produces an annual summary report on occupational exposure in Canada and participates in research projects [33].

It is important to appreciate the dose descriptions used in radiation protection. For the purpose of this thesis, three terms are important: 1. **Absorbed dose** (J/kg, special unit: gray, Gy) refers to the amount of energy deposited in the tissue. It is important to note that the effects of radiation vary depending on the type of radiation being considered. 2. **Equivalent dose** (J/kg, special unit: sievert, Sv) is the absorbed dose multiplied by a radiation weighting factor; gamma rays and x-rays have a factor of one. To account for biological effectiveness, the tissue irradiated is also considered. 3. **The Effective dose** (J/kg, special unit: sievert, Sv) is the equivalent dose multiplied by a tissue weighting factor. The tissue weighting factors are empirical estimates, and acknowledge both deterministic and stochastic effects of radiation. These weighting factors permit the calculation of whole-body dose by summing relative contributions from individual organs. The effective whole-body dose is often used in occupational radiation protection as it best correlates with stochastic disease.

The Provincial Government of Newfoundland and Labrador sets maximum dose for radiation workers under the Radiation Health and Safety Act. Licensee must ensure workers do not receive an effective dose over the set dose limits (Table 1.2). If an effective dose is received higher than the given limits, the proper safety measures must be taken.

Table 1.2. *Effective dose limits*

Person	Dosimetry Period	Effective Dose (mSv)
Radiation worker	13-weeks 52-weeks	30 50
Person who is not a radiation worker	52-weeks	5

Operationally one measures radiation exposure as an equivalent dose. Licensees follow the same guidelines to ensure workers stay below the dose limits.

- In a one-year dosimetry period, the equivalent dose received to the skin, bone, and thyroid of a radiation worker should not exceed 300 mSv, and 30 mSv annum for any other person not employed as a radiation worker [7].
- In a one-year dosimetry period, the equivalent dose received to the hands and feet of a nuclear energy worker should not exceed 750 mSv, and 75 mSv annum for any other person not employed as a radiation worker [7].

The Provincial Radiation Health and Safety Act [31] [7] communicates many of the same guidelines and procedures discussed in the national Nuclear Safety and Control Act. Each act includes three main elements: the management of occupation radiation, the assessment and monitoring of exposure to personnel, and the steps to communicate radiation protection regulations to workers. Three of these elements sum to one overall incentive, to protect the health and safety of all radiation workers.

1.5 Fluoroscopy

Fluoroscopy is an imaging modality that allows real-time viewing of patient anatomy. A fluoroscopy system typically uses a pulsed x-ray beam source and varying frame rates to record the data, achieving movie-like images. During procedures requiring high temporal resolution (i.e., catheter placement), the frame rate and the dose are often high. Fluoroscopy is one of the most versatile image modalities. It can be used to visualize joints or x-ray contrast media moving throughout the body, cardiac and gastrointestinal systems, and biopsies.

Various configurations of fluoroscopy systems are tailored to certain exam types. There are systems better suited for gastrointestinal/genitourinary, and other systems like the C-arm that are more appropriate for surgery suites. Each design is made up of the same basic components,

including an x-ray tube, added filtration, beam collimator, and detector. The system's working parts allow for a low-dose, real-time visualization compared to other traditional static radiograph exams.

Fluoroscopy offers different modes of image acquisition. Continuous fluoroscopy uses a constant beam of radiation. The uninterrupted pulse can equate to a higher dose of radiation. Pulsed fluoroscopy breaks the beam into a series of short pulses. Continuous and pulsed fluoroscopy can be classified further as high or low dose modes. To achieve a similar signal to noise ratio (SNR) as continuous fluoroscopy while using the pulsed mode, the dose/pulse will have to be increased. A high-resolution image is not always necessary for accurate performance; therefore, pulsed fluoroscopy can be used with a low dose mode to deliver a much lower dose to patients. Frame rates can also be incorporated into the various modes of acquisition. A frame will capture the data during a set time period and display it as an image. While devices vary in design and use, a typical frame rate of 30 per second paired with 30 pulses provides continuous video-fluoroscopy. Any motion during the 1/30 of a second will blur the image. The blur can be reduced by delivering the same amount of radiation packaged in three brief pulses. The display rate will remain at 30 per second, so there will be three sets of ten identical images each second. This may cause image flicker. The number of pulses, the radiation per pulse, and the display (frame) rate can be adjusted to minimize the amount of radiation the patient receives. This is done at the expense of SNR (image quality). Additional dose-saving techniques like last frame hold, road mapping, and frame averaging have been accepted to help lower the dose even further during an exam.

During a fluoroscopy exam, the patient's body produces scattered radiation. Although orders of magnitude lower in intensity than the primary beam, this scattered radiation results in a small

dose to those attending the exam. There are mitigating factors: 1. Reducing patient dose necessarily reduces staff dose; 2. Staff further away receive less dose since the intensity of the radiation falls off with the square of the distance from the source (patient). 3. Staff may wear a protective gown (lead apron) to reduce the radiation intensity by an order of magnitude. However, for certain personnel it is necessary to stand near the patient and place their hands within the direct x-ray beam. In these cases, staff performing these procedures will receive a much higher dose than those whose duties allow them to stand further from the x-ray source.

1.6 Computed Tomography

Computed Tomography images are derived by combining data from many views or projections. The projection data is acquired by rotating a fan-shaped x-ray beam around the patient's body at a predetermined rate. A detector array collects the x-rays that are not attenuated by the patient's body. These projections are combined to form a cross-sectional image of the body. This process is repeated to span the lengthwise region of interest. CT scans generate 3D (volume) images of internal structures offering better contrast as compared to the 2D images. There are two reasons for this: first, overlapping tissue are not blended together. For example, liver attenuation is not modified by overlaying intestine attenuation. Second, the mathematical reconstruction algorithms can be adjusted to emphasize tissue type. Thus, regions of the body that comprise internal structures with similar densities can be easily distinguished from one another. CT makes imaging the brain, organs, bones, soft tissues, and blood vessels achievable. However, more radiation is required to achieve these gains in anatomical clarity. For example, where a chest x-ray might impart 0.8 mSv whole body dose, a chest CT will impart an effective whole-body dose near 6 mSv. Although interventional CT procedures are becoming more common, most CT

protocols are conducted with the staff remaining outside the procedure room. Thus, when considering stochastic disease for most CT procedures, it is the patients who are at risk.

In Canada, the most routinely scanned anatomical regions include the adult head, chest, and abdomen/pelvis, and pediatric head, chest, and abdomen [34]. Commonly pediatric chest or abdomen scans are used to detect malignancy or trauma, while adult head scans are used to diagnose cerebrovascular accidents or transient ischemic attacks and chest scans can help to detect known/suspected metastasis [34]. The continuous advancements in CT technology have increased the clinical possibilities of this imaging modality, which may result in the reliance of such exams to diagnose and a greater unnecessary radiation exposure to patients.

CT scan parameters are individualized based on the procedure and patient characteristics (e.g., weight). Parameters can be pre-set based on the anatomical region being scanned, or be modified by the operator. The parameters for standard CT scans include kV, mA, gantry rotation time, type of scan (helical or axial), scan direction, pitch, detector configuration, reconstruction kernels, and mA modulation parameters [12]. The parameters set will influence the diagnostic quality of the image and the dose to patient.

X-ray tube voltage (kV) can be defined as the energy that drives the x-ray generator tube. It is set by selecting the peak energy (kVp). A higher kVp will increase the penetrability of the x-ray beam through the patient. It also potentially reduces the contrast between hard and soft tissues. Scans are generally performed using a higher x-ray voltage (80 -140 kV) [12]. The x-ray tube current determines the rate at which x-rays are produced and is measured in milliamperes (mA). Adjusting tube current will directly affect patient dose; as mA is increased, patient dose will increase. Tube current can also be adjusted based on patient thickness. As the tube rotates around

the patient, the thinner anterior posterior view will receive fewer photons compared to the thicker lateral view. Tube rotation time refers to the time the x-ray generator tube takes to complete a full rotation. A faster rotation time will reduce overall scan time and potentially reduce patient dose. This is particularly important when scanning in axial mode, where the beam completes its rotation before moving along the patient; the data is collected slice by slice. On the other hand, with helical scans, the table continuously moves with an active x-ray beam. Slice data is obtained by interpolating the missing elements. A helical scan can be performed much faster than axial CT. Pitch and detector configuration are two additional parameters that can influence image characteristics. Pitch can be defined as the measurable distance between slices for helical scanning, while detector configuration determines the thickness of each slice for both axial and helical scanning.

1.7 Guidelines and Recommendations for CT Practice

The International Commission on Radiological Protection has identified four major reasons as to why patients are subject to increased radiation dose [35]:

- Assumption: Shorter scanning times (a shorter scan time is believed to radically reduce the radiation dose to the patient, but this is not the case. A shorter scan time will reduce radiation dose marginally, if at all).
- Practice: The image quality is much higher than necessary. The primary practice objective should be to ensure that an examination produces the necessary diagnostic information using the minimum required radiation to the patient.
- Medical review: Unjustified examinations. Healthcare professionals prescribing a medical imaging examination using radiation should ensure that the benefits outweigh the risks.

- Technical error: Improper setup or not availing of the dose-reducing features that the equipment provides.

Currently, no dose recommendations are set for patients undergoing a diagnostic examination. Because of the risk of stochastic effects during any CT scan, it is important that staff optimize patient dose for procedures, and that referring physicians consider which is the best test available. Various supports have been introduced to help healthcare workers manage radiation exposure to patients. Parallel with occupational protection, the ALARA principle may be applied to any medical imaging procedures. In theory, this principle would shunt patients to appropriate alternative procedures for diagnosis that do not use ionizing radiation (i.e., MRI and ultrasound). The ALARA principle can also be applied to CT procedures in the sense that any additional dose that does not have a direct benefit will not be applied. Campaigns such as Image Gently and Image Wisely have helped bring awareness to the danger of excessive CT scanning. Diagnostic Reference Levels (DRLs) are validated instrument-specific recommendations that help to identify abnormal radiation doses for various diagnostic protocols. The following recommendations help facilities develop scanning protocols for appropriate and safer CT use.

Image Wisely and Image Gently is a collaboration by health care organizations, including the American College of Radiology, Radiological Society of North America, American Society of Radiological Technologist, and The American Association of Physicists in Medicine to provide professionals and the public with appropriate education and awareness of radiation safety [36] [37]. The two campaigns orient their focus on different populations. Image Wisely supports the safety of adult patients, and Image Gently focuses on the safety of pediatric patients. Radiation safety information is provided for various modalities, including computed tomography, nuclear medicine, and fluoroscopy.

Registered medical imaging sites generate DRLs using guidelines outlined by the ICRP. The ICRP formally defines DRL as:

"A commonly and easily measured radiation metric for broadly defined types of equipment for typical examinations for groups of patients within an agreed weight range or, in certain specific circumstances, a standard phantom."

There are several caveats that healthcare professionals should be aware of regarding DRLs. DRLs are not to be applied to individual patients [38]. These standards were devised from a representative sample of patients undergoing a defined clinical procedure. DRLs are also not intended to be an equivalent for patient dose limits [38]. The tool is useful for optimizing procedures and for comparison purposes to establish whether a given dose was higher or lower than the median local, national, or regional dose value for a given procedure intending to protect patients from unnecessary bouts of radiation exposure.

DRL values are not static. Advancements in technology and protocol change can cause a shift in median dose values and should be reflected in existing DRLs [38]. The ICRP recommends national and regional DRLs be revised every 3-5 years, or more frequently if technology advancement and/or protocol change occur. If any medical imaging department happens to exceed the recommended DRLs, an investigation should be conducted to determine the reason.

There are a few factors that must be considered when setting DRL values [38]:

- Patient population characteristics (i.e., patient size/thickness).
- Choice of quantity (CTDI or DLP).
- Procedure selection and specifics (i.e., detector technology, detector configuration, image reconstruction algorithm).

- Imaging protocol (i.e., body region scanned, clinical task associated with procedure, tube potential, tube current, collimation, rotation time and pitch).

The first National level survey of CT practice in Canada was published in 2016 by Health Canada [34]. The survey gathered data from approximately 75% of CT equipment across the country. From the data, National DRLs were proposed for standard adult and pediatric CT examinations. DRLs were summarized as both CT dose index-volume (CTDIvol) per sequence (measured in mGy) and dose length product (DLP) per exam (measured in mGy · cm) for specified patient characteristics.

Table 1.3 *Summary of DRLs - median dose index values or "achievable doses" are shown in brackets.* [34]

	CTDIvol per sequence (mGy)	**DLP per exam (mGy · cm)**	**Age (yrs) [median]**	**Mass (kg) [median]**	**AP (cm) [median]**	**LAT (cm) [median]**
Adult Examinations						
Head	82 [66]	1302 [1044]	63	70.3	18.6	15.2
Chest	14 [9.5]	521 [362]	66	70.3	25.9	34.0
Abdo+Pelvis	18[13]	874 [609]	61	71.0	25.9	33.6
Chest+Abdo+Pelvis	17 [12]	1269 [931]	65	72	25.7	33.9
Pediatric Examinations						
Head (0 – 3 yrs)	37 [29]	578 [446]	1.5	10.0	15.6	13.2
Head (3 – 7 yrs)	49 [39]	843 [601]	6.0	20.0	17.1	14.0
Head (7 – 13 yrs)	57 [44]	888 [665]	10.0	32.0	17.6	14.5
Chest (0 – 3 yrs)	2.8 [1.5]	62 [40]	1.7	11.1	12.8	17.0
Chest (3 – 7 yrs)	3.8 [2.8]	87 [72]	5.0	18.0	14.9	21.3
Chest (7 -13 yrs)	4.8 [3.4]	136 [105]	9.5	31.0	17.7	26.0
Abdomen (0 – 3 yrs)	3.8 [3.0]	120 [130]	2.0	13.0	13.7	17.9
Abdomen (3 – 7 yrs)	4.9 [4.0]	185 [139]	6.0	22.0	15.0	20.7
Abdomen (7 – 13 yrs)	6.1 [4.9]	263 [194]	10.0	34.0	17,8	24.6

National DRLs have also been reported by many other countries, including the United Kingdom, Japan, Germany and the United States [39] [40] [41] [42], all with the common goal of improving patient radiation protection.

1.8 Patient Dose Rate vs. Staff Dose Rate

For the purpose of this research, it is important to understand the differences between patient dose and staff dose during interventional radiology and CT procedures. It is challenging to propose a relationship between the two without understanding both concepts. Little research has focused on examining a possible connection between the dose received during an interventional procedure for both staff and patient. Because of a patient's position within the x-ray beam, they will always receive a higher dose than any staff member that follows proper safety precautions. The staff dose is a fraction of that not absorbed by the patient. In other words, radiation scattered from the patient is the source of routine staff dose during fluoroscopy. Unlike radiation workers and the general public, no regulatory dose limits are established for patients receiving radiation-related medical care. An extensive review by the United States Government examined radiation doses to patients from interventional fluoroscopy procedures from 2006 to 2019 [43]. The review claims the values do not represent exact or expected radiation dose from fluoroscopy procedures but can be used for comparison purposes, or as an estimate of actual dose within an order of magnitude. Averaged effective whole-body dose values were reported for 15 different fluoroscopy examinations. Effective dose averages ranged from 44 mSv for abdominal arterial interventions to 0.2 mSv for venous access examinations. Ten of the 15 procedures had reported average effective doses over 5 mSv [43]. To compare, the average annual effective dose for Canadian radiation workers employed in the medical sector reported a value of 0.08 mSv [32]. This value represents a dose received over one year, while the averages reported from the patient

exam represent the dose received per procedure. To reduce exposure to the patient population, radiology departments utilize two initiatives: dose optimization and appropriate use of imaging services [44]. The optimization initiative refers to the ratio of image quality to radiation quantity (dose).

There are currently no regulatory limits on radiation use or irradiation time during a fluoroscopic or CT procedure, so operators need to be aware of the radiation levels for the safety of staff and patients [44]. Ideally, all fluoroscopy procedures would be conducted with efficient timing and a reduced field size to ensure the smallest localized dose rate. Angiography significantly contributes to radiation exposure to personnel because of the procedure's length of time and complexity. Cumulative air kerma is the unit calculated by the fluoroscope that represents the amount of kinetic energy reaching the reference point. In Canada, the maximum air kerma rate for fluoroscopes equipped with automatic intensity control is limited to 50 mGy/min, and 100 mGy/min for equipment that uses an automatic intensity control [44]. The source to image distance (SID) for mobile equipment must not be less than 30cm, or 38cm for stationary equipment [44]. There are some devices in place that help monitor and control the amount of output radiation during fluoroscopy procedures. Automatic exposure control devices (AEC) incorporated into fluoroscopic equipment adjust radiation levels based on patient anatomy and system positioning, and limit maximum radiation output levels below regulatory dose limits [44].

DRLs are predicted using a pool of consistent examinations of standardized patients or a replicated procedure using a phantom. DRLs cannot be used to predict patient dose from interventional procedures because of the variability in techniques, the uncertainty in dose measurement, the frequency of procedures, and the lack of published data available [44]. To estimate patient dose during a fluoroscopy procedure, three measures are considered. 1.

Entrance dose (milligray, mGy) is the radiation dose absorbed at the skin level of the patient. The measure is not often used to examine radiation risk to patients as it does not incorporate such parameters as tissue sensitivity factors or beam area. 2. **Organ dose** (millisievert, mSv) refers to the radiation dose to a patient organ. Each organ has a unique sensitivity factor that is included in the measure. Organ dose is important when estimating radiation risk to radiosensitive organs, including the thyroid and the reproductive organs. 3. **Dose area product** (kerma-area product, Gy.cm2) is the cumulative kerma multiplied by the area being irradiated. This value can be used to assess patient whole-body dose and stochastic risks [45]. Dose area product (DAP) can be used to estimate the effective dose by multiplying it by the appropriate organ coefficient. Effective dose can be used as a universal comparison unit between patients and staff.

A pre-selected reference point dose (Gy, mGy) can be used to estimate a patient's peak skin dose. The reference point dose (RPD) is point specific and is calculated for a fixed distance from the gantry isocenter along the central x-ray beam. This measurement can be helpful in estimating deterministic risk to patients [45]. Gantry motion, patient size, and patient location relative to the gantry will be reflective in estimating a patient's peak skin dose [45]. Some modern fluoroscopy systems can generate skin dose maps. These maps are a highly accurate estimation of a patient's peak skin dose. Different metrics are incorporated into the map output, including cumulative air kerma at the reference point, DAP, and gantry geometry [45].

Patient dose is not typically measured in real-time, because patients do not often wear personal dose monitors (like dosimeters) during an exam. The system output, whether it be entrance dose, organ dose, or DAP, must be used to derive a patient's effective dose before it can be compared to an occupational effective dose. Another discrepancy between patient and staff dose is the measurable period dose results are presented. Doses for healthcare workers are integrated over 3

months (quarterly), while patient doses are episodic (per procedure). For comparison, it would be impractical to quantify a staff dosimeter report from an episodic patient dose. The major source contributor of exposure also varies from staff to patient. Staff dose is primarily linked to radiation scattered from the patient, while patient dose is predominantly from the direct x-ray beam. Although the major source differs, the characteristic ability of the radiation to ionize does not.

Chapter 2 Literature Review

2.1 Current Research (Occupational Dose: Fluoroscopy Project)

A wealth of research is available evaluating patients' radiation doses for standard fluoroscopy procedures [45]. Very few studies examine radiation doses received by healthcare workers present during fluoroscopy procedures, and even fewer investigate a correlation between staff radiation dose and patient exposure during such procedures. The studies completed to prove or disprove a correlation have limitations, including focusing on a niche procedure type and using small sample sizes [46-49]. Results are also conflicting, with some studies suggesting a positive correlation between variables [46] [47] [49], and others indicating a poor correlation between staff dose and patient exposure [48]. All studies agree that further investigation is necessary before a conclusion can be made concerning a relationship between patient radiation exposure and staff dose.

The study by Mohapatra and colleagues (2013) compared patient doses collected from the imaging equipment to staff doses collected from personal dosimeters [46]. Comparisons were made between patient doses and doses received by all attending staff, including operators, scrub nurses, radiologic technologists, and anesthesiologists. Doses were collected for 39 cases, and

the study was limited to one procedure: endovascular thoracoabdominal aortic aneurysm repair using fenestrated endografts. Patient averages were calculated for fluoroscopy time (71.1 min), cumulative air kerma (6.979 Gy), and dose area product (540.9 Gy-cm^2). During the procedure, all staff wore protective lead aprons and thyroid collars. Personal dosimeters were worn outside the lead apron at neck level and were calibrated to measure whole body dose. Anesthesiologists (268 μSv) received the highest radiation dose followed by operators (125 μSv). Dosimeters worn by the scrub nurses (26 μSv) and radiologic technologists (19 μSv) received the lowest doses. Results showed a significant correlation between staff dose and patient DAP for the operators, scrub nurses, and anesthesiologists ($P < .05$). The equivalent dose received by the technologists was not correlated with DAP. Two additional variables, fluoroscopy time and cumulative air kerma, were determined to be weakly correlated with staff equivalent dose. Mohapatra and colleagues state a major limitation of the study was the variation in safety measures taken between health care workers. Both scrub nurses and anesthesiologist were located 7 feet (~2m) from the source, but anesthesiologists received much higher doses than scrub nurses. This may be attributed to scrub nurses receiving additional shielding from either a ceiling-mounted shield or the operator. With these limitations in mind, the study concluded occupational dose is better correlated with DAP, a measure linked to stochastic effects.

An additional study published in 2009 examined the correlation between staff radiation dose and patient exposure during pediatric interventional cardiology care [47]. To test the correlation, simulation exams were used. A biplane X-ray system was used to image polymethylmethacrylate plates with varying thicknesses; the polymethylmethacrylate plates serve as human phantoms. Three fluoroscopy modes (low, medium, and high dose), a cine mode, and three standard pediatric protocols (newborn, infant, and child) were tested at a fixed 22-cm field of view. Staff

radiation dose was measured using Unfors Instruments and expressed as dose equivalent. The Unfors Instrument was positioned to measure the dose received to the cardiologist's eyes with no shielding from safety goggles or ceiling-suspended screens. Results from the study concluded a positive linear correlation between scatter dose rates (mSv/h) and patient entrance dose rates (mGy/min) for all patient thicknesses. An estimation factor was proposed for this relationship: 10 mGy/min at the patient entrance would produce approximately 0.6 mSv/h scatter dose rates to the eyes of the cardiologist. A positive linear correlation was also established between DAP and scatter dose. For this correlation, an estimation factor of 7 μSv at the eyes of the cardiologist for 1 $Gy \cdot cm^2$ to the patient can be used to estimate radiation risk to staff using predetermined pediatric patient exposure values. In addition to these estimation factors, the study also addresses the properties of scattered radiation. An increase in scatter radiation by a factor of 92 was observed when moving from low to high fluoroscopy modes. A patient receiving a high dose will generate a corresponding increase in scattered radiation. This increase in scatter radiation puts staff at a higher risk for increased radiation exposure.

Earlier studies also investigated a correlation between patient and staff dose during interventional cardiology procedures. The first study completed by Tsapaki and colleagues (2005) concluded a poor correlation between patient and staff radiation dose [48]. The comparison was between patient dose measured as DAP and staff quarterly dosimeter readings from dosimeters placed on the left shoulder and left foot. The data was collected from cardiology departments in five different European countries. The authors concluded that variations in radiation protective measures between each country may explain the poor correlation. A second study conducted by Vano and colleagues (2006) concluded that different factors, including patient thickness and operation mode (low, medium, and high fluoroscopy modes), contribute to the relationship

between staff and patient dose [49]. Scatter dose rates at the position of the cardiologist were measured for different patient thicknesses and operational modes. Correlations between patient entrance surface air kerma rates and staff dose rates were established. For moderate patient thickness, the scatter dose rate was positively correlated with the patient entrance dose.

Additional research is necessary before a formal conclusion regarding a relationship between patient and staff radiation dose can be made. Current research is limited, and results between studies are conflicting. Existing studies often only correlated staff extremity dose, apparent eye dose, or unshielded dose with patient exposure, and excluded whole body dose from any comparison [47-49]. All studies examined only a small population with suspected variation between protective measures taken by health care workers. Some studies included doses from staff in various clinical roles, while others included just the operator. Although the operator is expected to receive a higher dose of radiation, this is not always the case. Scatter radiation from the patient can reach beyond the operator. Conclusions were also made based on limited types of procedures. To make an accurate correlation between staff and patient radiation dose, a comprehensive study is needed that would include the many types of procedures that involve fluoroscopy, a larger population, and detailed accounts of the protective measures taken by the health care workers involved in such procedures. An appropriate correlation with estimation factors can help health care workers predict risk and optimize procedure protocol to require only the necessary radiation dose to the patient.

2.2 Current Research (Patient Dose: CT Project)

The most recent review (2018 - 2021) of CT examinations performed in the Eastern Region of the province of Newfoundland has identified unexplained variation in radiation dose to

individual patients and radiation dose variation between hospitals in the same region (Kendall, personal communication). This dose variation can be driven by a number of factors, but an investigation of cause to our knowledge, has yet to be examined within the province. One proposed factor is the operator's discretion in selecting the technical parameters for the exam [50]. These parameters can affect both dose optimization and image quality. If this proves to be the case for the observed variation, optimizing patient doses to a consistent standard can be achievable by modifying and monitoring the protocols implemented to help reduce unnecessary radiation dose to patients [50]. Other regions have also reported similar variation in radiation dose from standard CT examinations between patients, institutions, and countries [50-56]. Other factors including patient population differences, inconsistencies in data collection and analysis, machine characteristics (manufacturer and model), and institution type (academic, trauma-focused centre, or 24 h/day provider of CT), may also be contributing to dose variation [50].

A prospective cohort study by Smith-Bindman and colleagues investigated the international variation in radiation dose for standard CT procedures [50]. Data was collected from a dose registry, including dose data (effective radiation dose) from seven countries (Switzerland, Netherlands, Germany, United Kingdom, United States, Israel, and Japan). Abdomen, chest, combined chest and abdomen, and head protocols in adults aged 18 years and older were included in the study. Examinations were performed on 290 machines from four manufacturers and 49 machine models. After accounting for patient characteristics, the highest variation in effective dose was observed for abdomen and combined chest and abdomen CT protocols [50]. The dose data was adjusted based on different parameters hypothesized to be associated with the received radiation dose. A multivariable analysis concluded that most of the hypothesized factors (patient population, institutional characteristics, machine manufacturer and model) had a small

effect on the dose variation observed between different machines and countries. The variation between countries was driven mainly by technical parameters set by operating staff, which may reflect the parameter ranges assumed to be necessary for optimal image quality [50].

A recent survey by Tonkopi and colleagues compared DRLs for standard CT exams and observed variation at national and local levels [51]. The survey included dose data from eight CT scanners located within two clinical locations in Oslo, Norway and four CT scanners, all located within different regions of Nova Scotia, Canada. The data represented three machine manufacturers and eight different machine models. The survey selected dose data for three routine examinations using standard CT protocol: non-enhanced head, contrast-enhanced thorax, and contrast-enhanced scan of the abdomen pelvis for average-sized adult patients. Local diagnostic reference levels (LDRLs) were given as CTDIvol and DLP for both countries. Compared to Norwegian LDRLs, Canadian LDRL values were 9%-13% lower for the three routine examinations considered. Significant dose variation was also reported for hospitals located in the same country. Hospital #2 in Norway recorded higher median doses than hospital #1: 29% for the abdomen and pelvis and 44% for thorax scans. Significant variation was also found between dose values from identical machine models located in different hospitals. The Canadian Siemens Definition Flash yielded much lower doses than the same model located in Norway when similar scanning protocols were used. The lower doses reported in Canada may be explained by dose reducing measures implemented in Nova Scotia following provincial survey results on DRLs [51]. The authors concluded that the considerable variation observed between countries, regions, and identical models proves a need for CT protocol optimization.

A systematic review completed in 2019 examined current adult national DRLs in head, chest, and abdomen pelvic CT scans [52]. The study included reported DRLs for DLPs and/or CTDIvol

from 51 countries, but addressed some limitations including some countries' exclusion of protocol characteristics such as the type of CT scanner and image reconstruction algorithms applied. In addition, some of the reported DRLs were not accompanied by patient demographic characteristics. Many DRLs were reported over 5 years ago including national diagnostic reference levels (NDRLs) from Canada and the USA. These doses do not align with the ICRP recommendation to revise such values every 3-5 years. These DRLs may, therefore, not be reflective of protocol changes or technological advances. The review noted a wide range in the dose data for all three examination types. Among the 51 countries, dose length product DRLs ranged from 799-1359, 330-707, and 550-1486 mGy · cm for head, chest, and abdominal CT scans, respectively. The volume CT dose index DRLs ranged from 30.4-85.5, 9-15 and 12.3- 31 mGy · cm for head, chest and abdominal CT scans, respectively. The authors credit the role of DRL comparison in helping to improve radiation delivery monitoring and protocol optimization.

Patient dose variation has also been observed within a single institution for patients receiving the same CT scan. Cohen and colleagues investigated a range of patient doses from non-contrast CT of the head and abdomen/pelvic scans within a single institution [53]. The authors hypothesized that minimal variation between patient dose would exist within a radiology department due to the reuse of protocol and shared staff [53]. After controlling for patient BMI and scanner type, variation was present for CT radiation dose (recorded as dose length product) during abdomen pelvic and head CT scans performed at a single institution. A 6-fold variation in radiation dose was found for abdomen pelvic CT scans; it was a 2.5-fold difference after controlling for BMI and scanner type. Two additional studies examining radiation dose in patients undergoing a standardized procedure reported consistent findings [54] [55].

The first study collected and compared dose data from 1,582 patients who underwent CT scans for suspected urolithiasis [54]. The median effective dose data across the 15 hospitals varied by 5-fold ranging from 4- 19 mSv. A 200-fold variation was reported in dose between patients. The observed variation persisted even after patient and hospital factors were controlled for. A similar study with the purpose of examining radiation dose from scans using renal colic protocols offered comparable findings [55]. Dose data was extracted from the Dose Index Registry (DIR) and included scans performed to detect kidney stones in patients aged 19 years and older and represented data from 93 institutions. Mean DLP ranged from 307 to 1,497 mGy · cm (4.6- 22.5 mSv) between the 93 institutions, and median DLP ranged from 235 to 1,320 mGy · cm (3.5-19.8 mSv). The authors concluded that there is a large variation in patient radiation dose between different clinical centres. The authors stated a minor contribution of patient population factors and CT scanner type to patient dose variation. Their study addressed the major contributor to dose variation as the technique parameters used (tube current, peak kilovoltage and pitch).

To our knowledge, no explanation for universally observed CT dose variation has been proved. Large scale population-based studies are limited due to the lack of information crucial for such a study (patient size, machine manufacture/model, and protocol features) [53]. Some studies have suggested that technique parameters set by operator staff have driven the observed variation in patient dose during CT examinations [50] [55]. Efforts to reduce the variation for frequently performed CT examinations through protocol change was tested in a study by Tonkopi and colleagues [56]. Dose data was collected from 16 CT scanners located across the province of Nova Scotia. The data represented doses from nine different models and four manufacturers. Data included the five most frequently performed CT examinations (chest, low dose chest, head, combined abdomen and pelvis, and combined chest, abdomen and pelvis). Each hospital was

assigned a mean DLP which was evaluated against each of the site's and province's DRLs. The results concluded that there is a wide variation in radiation dose between hospitals located within the same province, as a 2-fold to 5-fold difference in radiation dose was reported. However, there were no statistically significant differences in image quality. Controlling for the number of detector rows and scanner age proved a very weak correlation on the effect in patient dose variation. The variation in patient dose between hospitals and identical scanners for frequently performed CT examinations was demonstrated to be primarily driven by technique parameters chosen by operator staff. Scanners that reported the highest doses were recommended protocol optimization strategies. After implementing the strategies, radiation doses were reduced by 31-41% with no decrease in image quality.

The province of Newfoundland and Labrador has yet to report local DRLs for CT examinations performed within the province. The Eastern Health Region has established DRLs for most common CT protocols. A review of mean dose imparted for six common scans identified variation among six hospitals in the same region (Kendall, personal communication). Further investigation is necessary to determine the significance of the potential variation. Such a study will help contribute to existing literature examining CT dose variation among patients, institutions, and countries. The findings may help to build a case around the possibility of technique parameters being set by the operator as the cause for such variation. We also hope to address the importance of setting DRLs and adhering to the 3-5 year follow up recommended by ICRP. If consistent findings are found, dose-optimization strategies can be recommended to support the health and safety of patients undergoing CT examinations within provincial medical imaging departments.

Chapter 3 Methodology

3.1 Methodology (Patient Dose: CT Project)

This retrospective study analyzed computed tomography protocol data that contained no patient or hospital identifiers. The data was obtained through the auspices of Dr. E Kendall, Faculty of Medicine, Memorial University. The exams were performed on six instruments: four Canon Aquilion, one General Electric Lightspeed, and one Phillips Brilliance. CT imaging suites were coded H1-H6 and referred to as sites or locations.

The protocols were performed through the period January 2018 to September 2021 inclusive. The protocol information extracted was: protocol name, exam date, gender, age, site ID (H1-H6), CTDIvol (an estimate of cross-sectional dose), dose length product (DLP, an estimate of dose administered), effective dose, and scan length. The study was restricted to cases listing ages 19 years and greater at the time of examination.

The data contained records for approximately 400 distinct protocols. Of these, the most frequently performed protocols were selected for analysis. These were: routine head with contrast, routine head without contrast, routine head with and without contrast, chest with contrast, chest without contrast, chest abdomen pelvis with contrast, chest abdomen pelvis without contrast, lumbar spine, pulmonary angiogram, abdomen pelvis with contrast, abdomen pelvis without contrast, and renal colic. Although the data was provided grouped as quarters, all quarters were combined into their year to conduct analysis. Quarter four data was unavailable for 2021, and fourth quarter data for renal colic protocol was unavailable for 2018.

Each site used customized names therefore, the dataset was first filtered to group similar scans under standardized, common protocol names. Once data grouping was completed, the nine parameters were extracted under normalized protocol names.

Statistical analysis, including summary statistics, one-way analysis of variance, and pairwise comparisons, was carried out using Minitab statistics software, version: 21.4.2 (64-bit). All graphical representations (box-whisker plots) were created using Minitab, version 21.4.2.

One-way analysis of variance (ANOVA) was applied for each comparison with significance set to 0.05. The predominance of results yielded significant variation among sites. Tukey Pairwise Comparison test was used in conjunction to ANOVA to assess the significance of differences between site pairs and within sites for reported mean CT scan metrics. Differences between and within site scan metrics were reported as a t-test statistic with corresponding p-value. Significance was declared at < 0.05.

Pairwise comparisons for dose, CTDIvol, and scan length were performed for all combinations of sites in 2018. Comparisons were also performed for all combinations of years for the same sites. These tests allowed for the comparison between and within CT imaging suites in the province of Newfoundland and Labrador.

Box and whisker plots were used to compare the distribution of technical parameters and protocol dose between sites. Boxes indicate interquartile range, the cross inside the box reflects the mean, whiskers are drawn to minimum and maximum values above and below the box which exclude outliers, stars indicate outliers, and the horizontal line in the box represents the median. Each datapoint represents an individual exam; 50% of the data points are found within the box, separated by the median (2^{nd} and 3^{rd} quartiles), while 25% are found in each whisker (1^{st} and 4^{th}

quartiles). Box and whisker plots help to describe how much variance is in each dataset and how much variance is present within each quartile. Visual comparisons can be made between the different plot characteristics.

A dataset containing a larger variance is demonstrated when boxes and whiskers are longer, extending further across the y-axis. If the distribution is symmetric, the data will be evenly split at the median with quartiles approximately equal. Skewness can also be interpreted from the plots. The distribution is positively skewed when whiskers and half-box are longer above the median than on the bottom, below the median. In a positively skewed data set, data points are clustered within the upper quartiles (3^{rd} and 4^{th}), for a negatively skewed dataset, data points are clustered within the lower quartiles (1^{st} and 2^{nd}). For the purpose of this project, the main objective was to compare mean protocol values between instruments. Only subjective comparisons can be made regarding the distribution of data. Statistical analysis was not conducted to complement comparisons of data distribution between instruments.

3.2 Methodology (Occupational Dose: Fluoroscopy Project)

This retrospective study aimed to analyze two datasets for potential correlations between staff dosimetry readings and patient radiation dose during fluoroscopy procedures. The patient data set contained no patient or hospital identifiers. Patient Reference Point Dose or Dose Area Product data was obtained from Eastern Health and extracted by a second party data custodian. A second data set provided anonymized dosimetry data from health professionals performing fluoroscopy procedures in the Eastern Health region; data was obtained from Eastern Health and extracted by a second party data custodian.

The fluoroscopy procedures were performed from October 2016 to September 2021, inclusive. Patient and protocol data were organized as fiscal quarters (quarter one starts April 1 and ends June 30, etc.), with years 2017 to 2020 containing all four quarters, and years 2016 and 2021 containing two fiscal quarters. The examination information extracted was: procedure name, date performed, total dose area product (DAP) ($Gy.cm^2$), total reference point dose (RPD, mGy), kVp (kV), mA, and exposure time (s) when provided. Quarters that contained all variables include 2019 quarter 3, all quarters in 2020, and quarters 1 and 4 in 2021. The requested variables RPD, kVp, mA, and exposure time were missing for the remainder of the quarters. The protocols were limited to patients that underwent cardiac and vascular radiographic procedures. RPD was the chosen variable to correlate against dosimetry data. RPD was available from quarter 3 2019 to quarter 1 2020 (seven quarters total) and missing from quarter 3 2016 to quarter 3 2019 (twelve quarters total). The exponential relationship between RPD and DAP was first linearized using log transformation. In addition to linearizing the data, the transformation was an attempt to normalize the data. Correlation testing and simple linear regression were used to investigate the relationship between log(RPD) vs. log(DAP), and scatterplots were used for visualization. Regression performance was evaluated using two regression statistics: correlation coefficient (r) and R^2 score. Regression equations (slope) were compared over four fiscal quarters in 2020. Linear trendlines, linear regression equations, and model summary statistics were reported for each regression model. Statistical analyses were performed using IBM SPSS Statistics software, version: 28.0.1.0 (142) and all graphical representations were created using Microsoft Excel, version 2302.

RPD was given per exposure instance and therefore had to be summed to reflect the total RPD per exam. DAP was given in units of $Gy.cm^2$.

Dosimeter data contained de-identified occupational dosimeter readings from October 2016 to September 2021, inclusive. Dosimeter readings were organized by fiscal quarters, with quarters matching those from the patient fluoroscopy data set. The data only included health care professionals involved in cardiac and vascular procedures. Other extracted variables included professional type (registered nurse, medical radiation technologist, and radiologist), gender, and quarterly occupational dose by exposure site. Dosimeter readings were either a numerical value or a letter indicating a dose equivalent below the detectable reading. The dataset also indicated when a badge was not submitted for reading; these are the missing values in the dataset. The dosimetry service provider for the Eastern Health region changed during the study period with the main difference being the minimum detectable dose. The change to Landauer Dosimetry Service (LDS) occurred during fiscal quarters one and two of 2018, which was preceded by the National Dosimetry Service (NDS). NDS recorded a minimum detectable dose of 0.1 mSv, whereas LDS can detect a minimum dose of 0.01 mSv. Dose equivalents below the minimum were not recorded as missing values but instead replaced with 0.00 mSv to count for a recorded value. A frequency table of missing occupational dose data has been provided (Table 4.15)

Chapter 4 Results and Analysis

4.1 Distribution of Radiation Doses and Exam Scan Length by Hospital (2018)

Dose estimates and underlying technical parameters were obtained for twelve routine computed tomography exams performed at six CT sites. The objective was to determine if patients received a similar dose for a similar exam protocol. When significant differences were noted, the technical parameters were referenced to determine the source of the differences. Sites were compared using data from 2018, whereas year-to-year comparisons used data from 2018 to 2021. Table 4.0

lists the protocols examined and the total number of cases obtained from each site in 2018. There were significant case number differences among sites, therefore the Tukey Pairwise comparison test was selected to measure significant difference in site means and control for type 1 error.

Table 4.1 *Total cases obtained from 2018 for each protocol by hospital*

Protocol	Scan region	H1	H2	H3	H4	H5	H6
APC-	Abdomen Pelvis	188	417	108	488	268	425
APC+	Abdomen Pelvis	499	1268	476	1784	983	2045
CAPC-	Chest Abdomen Pelvis	72	116	32	80	167	81
CAPC+	Chest Abdomen Pelvis	316	973	528	620	1533	957
CC-	Chest	165	362	331	405	815	758
CC+	Chest	178	542	358	368	430	704
LS	Lumbar Spine	325	776	313	388	1181	533
PA	Chest	47	196	654	544	110	311
RCOL	Abdomen	156	409	138	440	337	349
RHC-	Head	545	774	532	2155	625	1414
RHCC	Head	49	690	32	263	137	307
RHC+	Head	161	125	333	410	346	586

To test the hypothesis that hospital sites delivered statistically similar doses using similar technical parameters, a Tukey Pairwise Comparison test was performed. Differences between factors were reported as a t-test statistic with corresponding p-value.

The Tukey Pairwise Comparison test detected significant differences ($p < 0.05$) for CTDIvol, effective dose and mean scan length between most site pairs for most protocols. These differences are explored in greater detail in the following sections. The interpretation will reference graphical representations of analyses (box and whisker plots) and summary tables showing grouping information using the Tukey method and 95% confidence. Means that do not share a letter are significantly different ($p <0.05$). Tabular results are available in the appendices (Table A.14-A.15).

Effective dose (mSv), CTDIvol (mGy), and scan length (mm) were compared site to site for each of the protocols listed in Table 4.1. For this pairwise comparison, the dataset referenced scan activities performed in 2018 at six hospital sites.

4.1.1 Abdomen Pelvis without Contrast (APC-)

The dataset contained 1,824 (APC-) exams, but these were unevenly distributed over the sites. Tukey pairwise comparison test was selected to measure significant difference in site means. Means that do not share a letter are significantly different ($p < 0.05$) (Table 4.2).

Table 4.2 *Grouping information for abdomen pelvis without contrast exam variables using the Tukey Method and 95% confidence (2018)*

[A] CTDIvol (mGy)

Hospital Site	Mean	Grouping
H1	9.30	B
H2	10.62	B
H3	14.44	A
H4	10.69	B
H5	15.22	A
H6	9.66	B

[B] Scan Length (mm)

Hospital Site	Mean	Grouping		
H1	513.20		B	C
H2	578.64	A		
H3	485.89			C
H4	525.82		B	C
H5	537.33		B	
H6	533.08		B	

[C] Effective Dose (mSv)

Hospital Site	Mean	Grouping			
H1	6.95				D
H2	8.87		B	C	
H3	10.18	A	B		
H4	8.19			C	D
H5	11.91	A			
H6	7.59				D

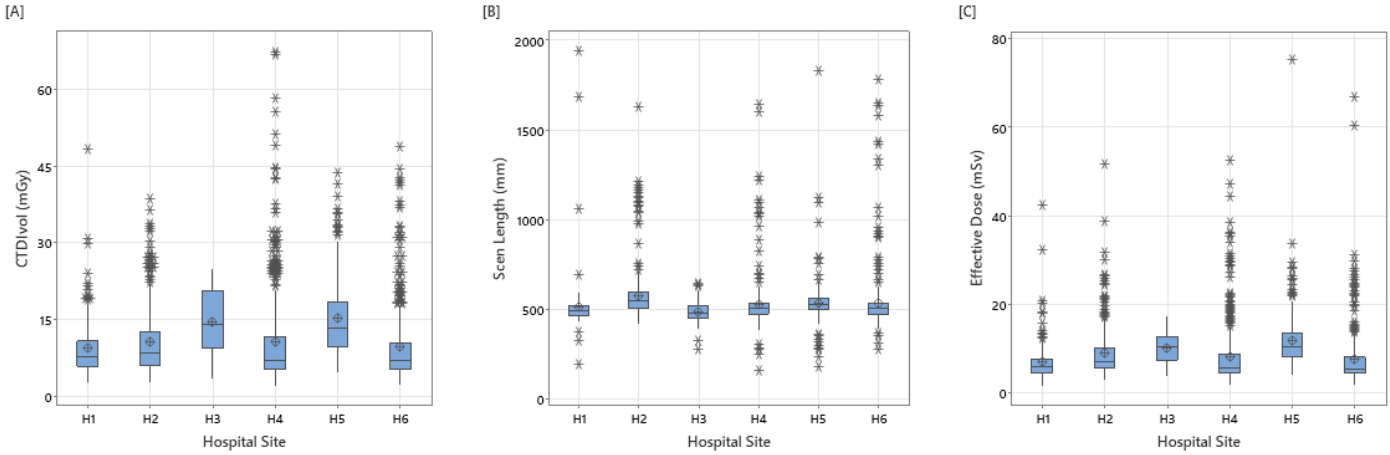


Figure 4.1 [A-C]: Abdomen pelvis without contrast: A. CTDIvol (mGy) B. Scan Length (mm) C. Effective Dose (mSv). Represents the distribution of dose (CTDIvol and effective dose) and

technical parameters (scan length) by hospital for APC- protocols performed in 2018 for six hospital sites.

CTDIvol: The CTDIvol means ranged from 9.30 $\pm$ 5.53 mGy to 15.22 $\pm$ 7.38 mGy (Table A.1). Figure 4.1-A provides the CTDIvol data distribution for the APC- protocol. Most hospitals exhibited non-symmetric quartiles with a mean greater than the median. H3 exhibited approximately symmetric quartiles and a mean that intersected the median. The CTDIvol means differed among the sites, but H1 cf H2 cf H4 cf H6, and H3 cf H5 exhibited significantly similar means.

Scan Length: Mean scan lengths for APC- ranged from 485.89 $\pm$ 57.22 mm to 578.64 $\pm$ 135.95 mm (Table A.2). Figure 4.1-B provides scan length data distribution for the APC- protocol. Scan lengths between sites displayed significant variation and similarity (Table 4.2). Hospital 2 had a significantly greater scan length than the other sites.

ED: Effective dose averages ranged from 6.95 $\pm$ 4.47 mSv to 11.91 $\pm$ 6.18 mSv (Table A.3). Figure 4.1-C provides the effective dose data distribution for the APC- protocol. H3 distribution can be described as approximately symmetric, with data being split at the median. The remaining sites featured data clustered within the upper quartiles (3^{rd} and 4^{th}). Dose means significantly varied for the preponderance of sites. The sites were grouped by their similarity between ED means as follows: H3 cf H5, H2 cf H3, H2 cf H4, and H1 cf H4 cf H6.

4.1.2 Abdomen Pelvis with Contrast (APC+)

The dataset contained 7,055 exams (APC+), but these were unevenly distributed over sites.

Tukey pairwise comparison test was selected to measure significant difference in site means.

Means that do not share a letter are significantly different ($p < 0.05$) (Table 4.3).

Table 4.3 *Grouping information for abdomen pelvis with contrast exam variables using the Tukey Method and 95% confidence (2018)*

[A] CTDIvol mGy)

Hospital Site	Mean	Grouping
H1	9.84	C
H2	10.78	C
H3	14.49	A
H4	12.07	B
H5	14.09	A
H6	11.76	B

[B] Scan Length (mm)

Hospital Site	Mean	Grouping
H1	501.90	D
H2	554.76	A
H3	521.63	C
H4	519.61	C
H5	534.05	B
H6	505.24	D

[C] Effective Dose (mSv)

Hospital Site	Mean	Grouping
H1	10.60	A
H2	8.78	C
H3	11.47	A
H4	9.46	B
H5	11.40	A
H6	8.84	C

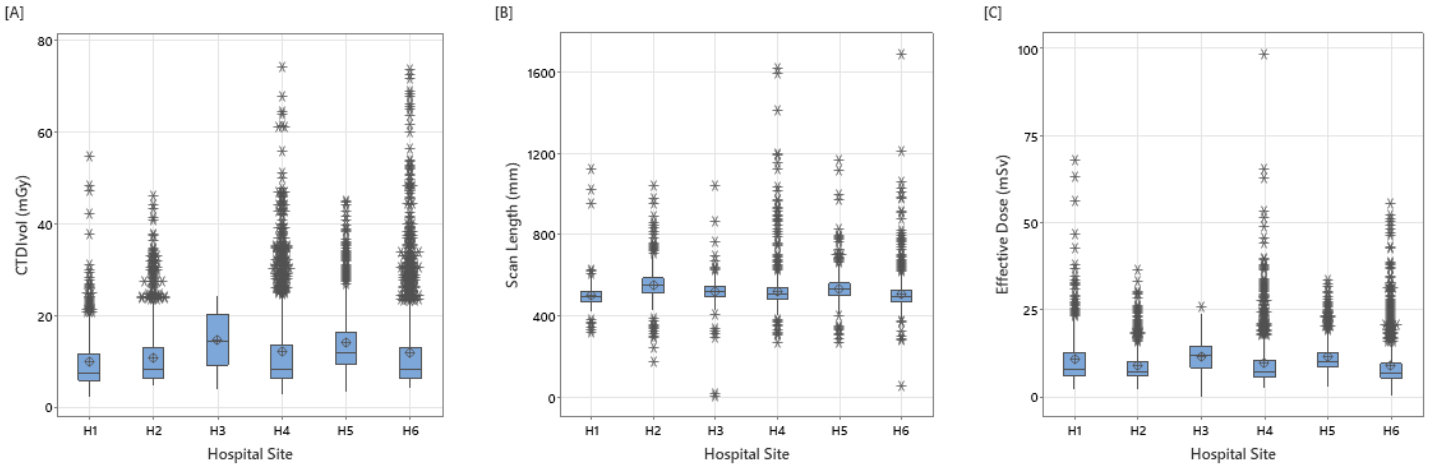


Figure 4.2 [A-C]: Abdomen pelvis with contrast: A. CTDIvol (mGy) B. Scan Length (mm) C. Effective Dose (mSv). Represents the distribution of dose (CTDIvol and effective dose) and technical parameters (scan length) by hospital for APC+ protocols performed in 2018 for six hospital sites.

CTDIvol: The CTDIvol mean values ranged from 9.84 $\pm$ 6.57 mGy to 14.49 $\pm$ 5.72 mGy (Table A.1). Figure 4.2-A provides the CTDIvol data distribution for the APC+ protocol. CTDIvol data is clustered above the median within the upper quartiles (3rd and 4th). Apart from H3, CTDIvol means are greater than the medians and outliers are present above the mean. The CTDIvol means varied among sites but H3 cf H5, H4 cf H6, and H1 cf H2 exhibited similar means.

Scan length: Mean scan lengths for APC+ exams ranged from 501.90 $\pm$ 55.72 mm to 554.76 $\pm$ 67.15 mm (Table A.2). Outliers are present above and below each site's mean. Mean scan lengths observed in H3 cf H4, and H1 cf H6 were similar while the remaining thirteen site pairs significantly differed.

ED: Effective dose averages ranged from 8.84 + 5.98 mSv to 11.47 + 3.72 mSv (Table A.3). Outliers failing above the mean are present for all hospital sites. Most hospitals exhibit mean values greater than the median. Dose averages significantly varied between eleven site pairs but H1 cf H3 cf H5, and H2 cf H6 reported similar means.

4.1.3 Chest Abdomen Pelvis without Contrast (CAPC-)

The dataset contained 548 exams (CAPC-) but these were unevenly distributed over the sites. Tukey pairwise comparison test was selected to measure significant difference in site means. Means that do not share a letter are significantly different ($p < 0.05$) (Table 4.4).

Table 4.4 *Grouping information for chest abdomen pelvis without contrast exam variables using the Tukey Method and 95% confidence (2018)*

[A] CTDIvol mGy)

Hospital Site	Mean	Grouping	
H1	7.56		B
H2	9.19	A	B
H3	11.60	A	
H4	10.07	A	
H5	10.18	A	
H6	9.29	A	B

[B] Scan Length (mm)

Hospital Site	Mean	Grouping		
H1	687.39			C
H2	741.50		B	
H3	839.79	A		
H4	706.15		B	C
H5	864.39	A		
H6	659.70			C

[C] Effective Dose (mSv)

Hospital Site	Mean	Grouping	
H1	7.87		B
H2	9.82		B
H3	16.25	A	
H4	9.67		B
H5	14.00	A	
H6	8.86		B

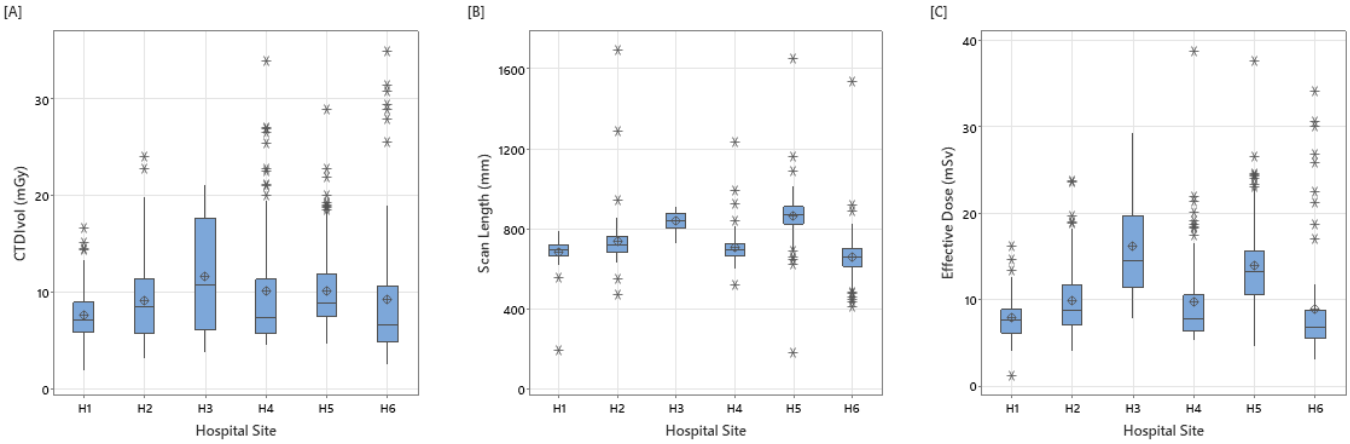


Figure 4.3 [A-C]: Chest abdomen pelvis without contrast: A. CTDIvol (mGy) B. Scan Length (mm) C. Effective Dose (mSv). Represents the distribution of dose (CTDIvol and effective dose) and technical parameters (scan length) by hospital for CAPC- protocols performed in 2018 for six hospital sites.

CTDIvol: The CTDIvol mean values ranged from 7.56 $\pm$ 3.04 mGy to 11.60 $\pm$ 5.84 mGy (Table A.1). CTDIvol values for CAPC- exhibited less variation. Mean CTDIvol values observed in H2 cf H3 cf H4 cf H5 cf H6, and H1 cf H2 cf H6 were similar. Outliers are present above the mean, and mean CTDIvol fell above the reported median for all sites.

Scan length: Mean scan lengths for CAPC- ranged from 687.39 ± 71.24 mm to 864.39 ± 111.55 mm (Table A.2). Average scan length observed for CAPC- procedures in H3 cf H5, H2 cf H4, and H1 cf H4 cf H6 were similar while the remaining ten pairs significantly differed. Outliers above and below the mean were usual in most datasets.

ED: Effective dose averages ranged from 7.87 ± 2.50 mSv to 16.25 ± 5.95 mSv (Table A.3). Outliers are scattered above the mean for the preponderance of sites with average dose falling above the median value. Statistical analysis indicates a significant difference in the effective dose averages between sites but H1 cf H2 cf H4 cf H6, and H3 cf H5 were similar.

4.1.4 Chest Abdomen Pelvis with Contrast (CAPC+)

The dataset contained 4,927 exams (CAPC+), which were unevenly distributed over sites. Tukey pairwise comparison test was selected to measure significant difference in site means. Means that do not share a letter are significantly different ($p < 0.05$) (Table 4.5).

Table 4.5 *Grouping information for chest abdomen pelvis with contrast exam variables using the Tukey Method and 95% confidence (2018)*

[A] CTDIvol (mGy)

Hospital Site	Mean	Grouping
H1	7.20	D
H2	9.20	C
H3	12.92	A
H4	8.86	C
H5	11.00	B
H6	9.02	C

[B] Scan Length (mm)

Hospital Site	Mean	Grouping
H1	899.01	B
H2	931.76	A
H3	855.31	E
H4	886.31	B C
H5	878.92	C D
H6	871.78	D

[C] Effective Dose (mSv)

Hospital Site	Mean	Grouping
H1	9.58	E
H2	12.82	C
H3	17.48	A
H4	12.15	C D
H5	15.17	B
H6	12.05	D

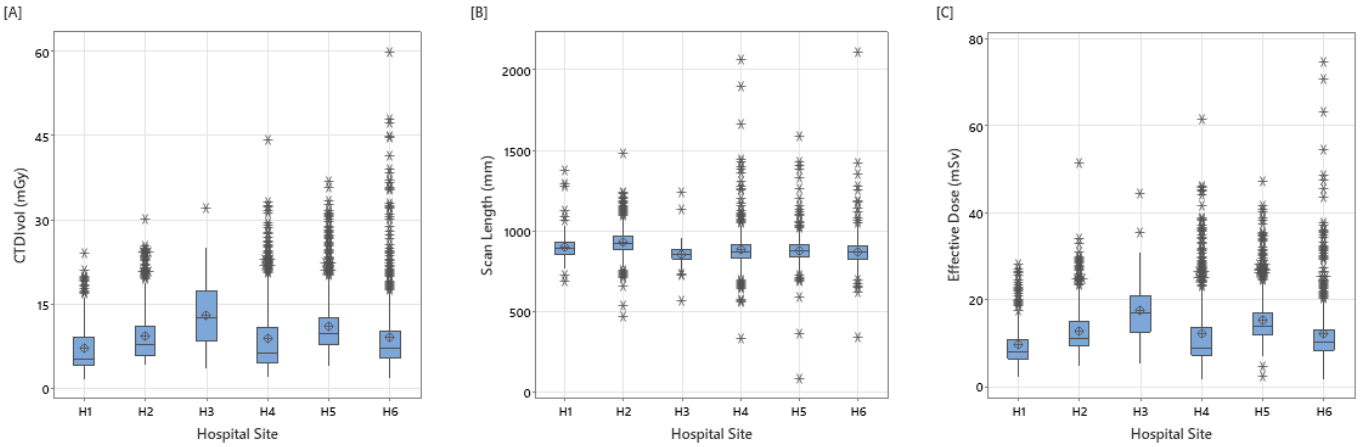


Figure 4.4 [A-C]: Chest abdomen pelvis with contrast: A. CTDIvol (mGy) B. Scan Length (mm) C. Effective Dose (mSv). Represents the distribution of dose (CTDIvol and effective dose) and technical parameters (scan length) by hospital for CAPC+ protocols performed in 2018 for six hospital sites.

CTDIvol: The CTDIvol mean values ranged from 7.20 $\pm$ 4.41 mGy to 12.92 $\pm$ 5.34 mGy (Table A.1). Excluding H3, mean CTDIvol values fall above the median with outliers located above the mean for all sites. The CTDIvol means varied among the sites but H2 cf H4 cf H6 exhibited similar means.

Scan length: Mean scan lengths for CAPC+ ranged from 855.31 $\pm$ 48.28 mm to 931.76 $\pm$ 79.81 mm (Table A.2). The dataset contained outliers above and below the means with a greater clustering above the mean. The Tukey pairwise comparison confirms that variation exists between mean scan lengths for site pairs but H1 cf H4, H4 cf H5, and H5 cf H6 were similar.

ED: The mean effective dose values ranged from 9.58 $\pm$ 4.94 mGy to 17.48 $\pm$ 6.02 mGy (Table A.3). Similar trends as the CTDIvol dataset were observed for the effective dose. The mean dose

observed for CAPC+ procedures significantly differed between sites with the exception of H2 cf H4, and H4 cf H6.

4.1.5 Chest without Contrast (CC-)

The dataset contained 2,903 exams (CC-), but these were unevenly distributed over sites. Tukey pairwise comparison test was selected to measure significant difference in site means. Means that do not share a letter are significantly different ($p < 0.05$) (Table 4.6).

Table 4.6 *Grouping information for chest without contrast exam variables using the Tukey Method and 95% confidence (2018)*

[A] CTDIvol (mGy)

Hospital Site	Mean	Grouping
H1	4.27	E
H2	8.61	C
H3	12.33	A
H4	4.80	E
H5	9.55	B
H6	7.45	D

[B] Scan Length (mm)

Hospital Site	Mean	Grouping
H1	433.28	A
H2	415.58	A
H3	360.44	D
H4	410.01	A B
H5	384.23	C
H6	395.19	B C

[C] Effective Dose mSv)

Hospital Site	Mean	Grouping
H1	3.19	D
H2	6.01	B
H3	8.20	A
H4	3.50	D
H5	6.21	B
H6	5.10	C

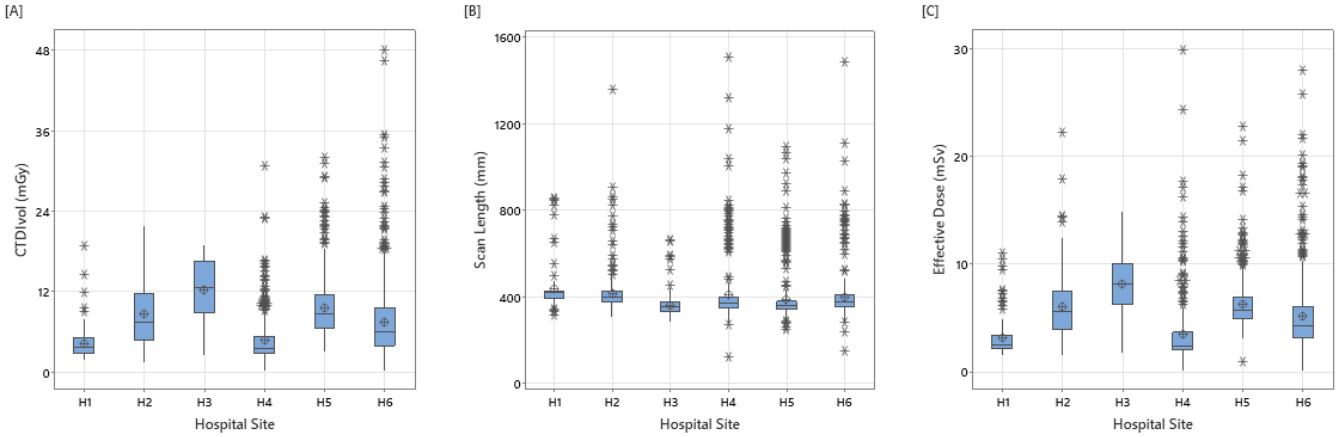


Figure 4.5 [A-C]: Chest without contrast: A. CTDIvol (mGy) B. Scan Length (mm) C. Effective Dose (mSv). Represents the distribution of dose (CTDIvol and effective dose) and technical parameters (scan length) by hospital for CC- protocols performed in 2018 for six hospital sites.

CTDIvol: The CTDIvol mean values ranged from 4.27 ± 2.24 mGy to 12.33 ± 4.64 mGy (Table A.1). Mean CTDIvol is greater than the median for the preponderance of sites. H1cf H4 cf H5 cf H6 exhibit outliers above the mean. Mean CTDIvol values observed for CC- procedures significantly differed between sites except H1 cf H4.

Scan length: Mean scan lengths for CC- ranged from 360.44 ± 45.05 mm to 433.28 ± 100.54 mm (Table A.2). Mean scan lengths do not intersect the median but rather fall toward the upper end of the dataset. Site exhibits outliers scattered above and below the mean. Statistical analysis indicates a difference between average scan lengths for most site pairs but H1 cf H2 cf H4, H4 cf H6, and H5 cf H6 mean scan lengths were similar.

ED: Effective dose averages ranged from 3.19 ± 1.79 mSv to 8.20 ± 2.56 mSv (Table A.3). Similar trends as the CTDIvol dataset were observed in effective dose. Means do not intersect the median but rather fall above, resulting in a clustering of data toward the upper quartiles. The mean doses significantly differed among thirteen site pairs but H2 cf H5, and H1 cf H4 exhibited similar means.

4.1.6 Chest with Contrast (CC+)

The dataset contained 2,580 (CC+) exams, but these were unevenly distributed over the sites. Tukey Pairwise comparison test was selected to measure significant difference in site means. Means that do not share a letter are significantly different ($p < 0.05$) (Table 4.7).

Table 4.7 *Grouping information for chest with contrast exam variables using the Tukey Method and 95% confidence (2018)*

[A] CTDIvol (mGy)

Hospital Site	Mean	Grouping
H1	3.92	D
H2	9.26	B
H3	11.99	A
H4	4.28	D
H5	9.65	B
H6	7.43	C

[B] Scan Length (mm)

Hospital Site	Mean	Grouping
H1	411.40	A
H2	404.33	A
H3	359.42	D
H4	378.70	B C
H5	369.20	C D
H6	385.06	B

[C] Effective Dose (mSv)

Hospital Site	Mean	Grouping
H1	2.35	D
H2	6.26	B
H3	7.89	A
H4	2.57	D
H5	6.25	B
H6	4.56	C

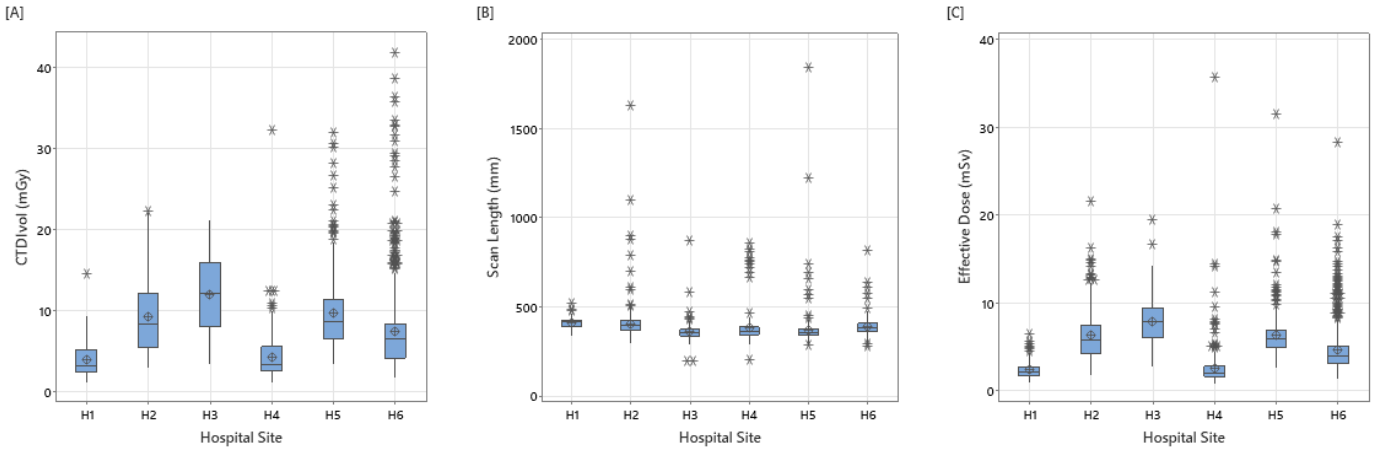


Figure 4.6 [A-C]: Chest with contrast: A. CTDIvol (mGy) B. Scan Length (mm) C. Effective Dose (mSv). Represents the distribution of dose (CTDIvol and effective dose) and technical parameters (scan length) by hospital for CC+ protocols performed in 2018 for six hospital sites.

CTDIvol: The CTDIvol mean values ranged from 3.92 $\pm$ 2.10 mGy to 11.99 $\pm$ 4.63 mGy (Table A.1). For CC+ exams, H4 cf H5 cf H6 contain many outliers compared to additional sites. Besides H3, CTDIvol values are clustered towards the upper quartiles. The CTDIvol means varied between site pairs but H2 cf H5, and H1 cf H4 exhibited similar means.

Scan length: Mean scan lengths for CC+ ranged from 359.42 ± 43.76 mm to 411.40 ± 26.95 mm (Table A.2). Site data contains outliers above and below the mean. Besides H1, mean scan lengths do not intersect the median but rather fall towards the upper end of the dataset, favouring the upper quartiles. Statistical analysis indicates a significant difference between average scan lengths for most site pairs. H1 cf H2, H4 cf H6, H4 cf H5, and H3 cf H5 exhibited similar mean scan lengths.

ED: Effective dose averages ranged from 2.35 + 0.94 mSv to 7.89 + 2.56 mSv (Table A.3). Outliers failing above the mean dose are present for each site, resulting in data clustering in the upper quartile range. Like CTDIvol, there is significant variation in average effective dose between hospitals but hospitals H2 cf H5, and H1 cf H4 exhibited similar means.

4.1.7 Lumbar Spine (LS)

The dataset contained 3,516 (LS) exams, but these were unevenly distributed over the sites. Tukey Pairwise comparison test was selected to measure significant difference in site means. Means that do not share a letter are significantly different ($p < 0.05$). (Table 4.8).

Table 4.8 *Grouping information for lumbar spine exam variables using the Tukey Method and 95% confidence (2018)*

[A] CTDIvol (mGy)

Hospital Site	Mean	Grouping		
H1	30.26		B	
H2	30.97		B	
H3	24.26			C
H4	30.85		B	
H5	38.04	A		
H6	30.28		B	

[B] Scan Length (mm)

Hospital Site	Mean	Grouping	
H1	245.86	A	
H2	224.12		B
H3	255.86	A	
H4	216.69		B
H5	251.05	A	
H6	253.39	A	

[C] Effective Dose (mSv)

Hospital Site	Mean	Grouping			
H1	18.97		B		
H2	17.86		B	C	
H3	15.48				D
H4	16.53			C	D
H5	23.56	A			
H6	19.07		B		

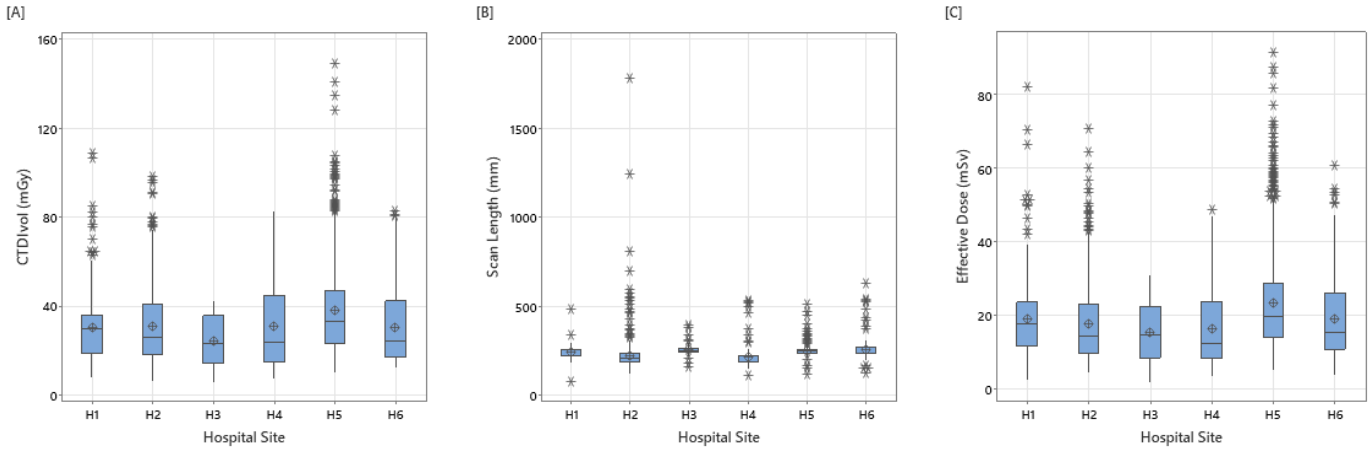


Figure 4.7 [A-C]: Lumbar spine: A. CTDIvol (mGy) B. Scan Length (mm) C. Effective Dose (mSv). Represents the distribution of dose (CTDIvol and effective dose) and technical parameters (scan length) by hospital for LS protocols performed in 2018 for six hospital sites.

CTDIvol: The CTDIvol mean values ranged from 24.26 $\pm$ 11.02 mGy to 38.04 $\pm$ 20.02 mGy (Table A.1). Figure 4.7-A provides CTDIvol site data distribution for the LS protocol. The preponderance of sites exhibited means greater than the median but H3 was approximately symmetric with a mean CTDIvol intersecting the median. Outliers are present for some sites and are located above the mean. From a total of fifteen site pairs compared, nine significantly differed while six exhibited similar average CTDIvol values.

Scan length: Mean scan lengths ranged from 216.69 $\pm$ 49.99 mm to 255.86 $\pm$ 21.32 mm (Table A.2). Site datasets contains outliers above and below the mean. H1 cf H4 cf H6 have median scan lengths located on quartile boundaries. H3 cf H4 cf H5 exhibit means that intersect the median and the remainder of sites report means that do not intersect the median. The mean scan lengths varied among sites but H1 cf H3 cf H5 cf H6, and H2 cf H4 exhibited similar means.

ED: Effective dose averages ranged from 15.48 ± 7.41 mSv to 23.56 ± 13.07 mSv (Table A.3). Similar data distribution trends as observed in CTDIvol dose can be extended to the effective dose; however, the mean effective dose exhibited more significant variation. H1 cf H2 cf H6, H2 cf H4, and H3 cf H4 had similar means while the remaining site pairs differed.

4.1.8 Pulmonary Angiogram (PA)

The dataset contained 1,862 (PA) exams, but these were unevenly distributed over the sites. Tukey Pairwise comparison test was selected to measure significant difference in site means. Means that do not share a letter are significantly different ($p < 0.05$) (Table 4.9).

Table 4.9 *Grouping information for pulmonary angiogram exam variables using the Tukey Method and 95% confidence (2018)*

[A] CTDIvol (mGy)

Hospital Site	Mean	Grouping
H1	10.56	B
H2	10.46	B
H3	16.77	A
H4	9.74	B
H5	16.60	A
H6	9.62	B

[B] Scan Length (mm)

Hospital Site	Mean	Grouping	
H1	388.69	A	B
H2	393.90	A	
H3	405.57	A	B
H4	365.65		B
H5	380.50	A	B
H6	366.65	A	B

[C] Effective Dose (mSv)

Hospital Site	Mean	Grouping	
H1	6.17	B	C
H2	7.43	B	
H3	12.76	A	
H4	6.47	B	C
H5	11.84	A	
H6	6.15		C

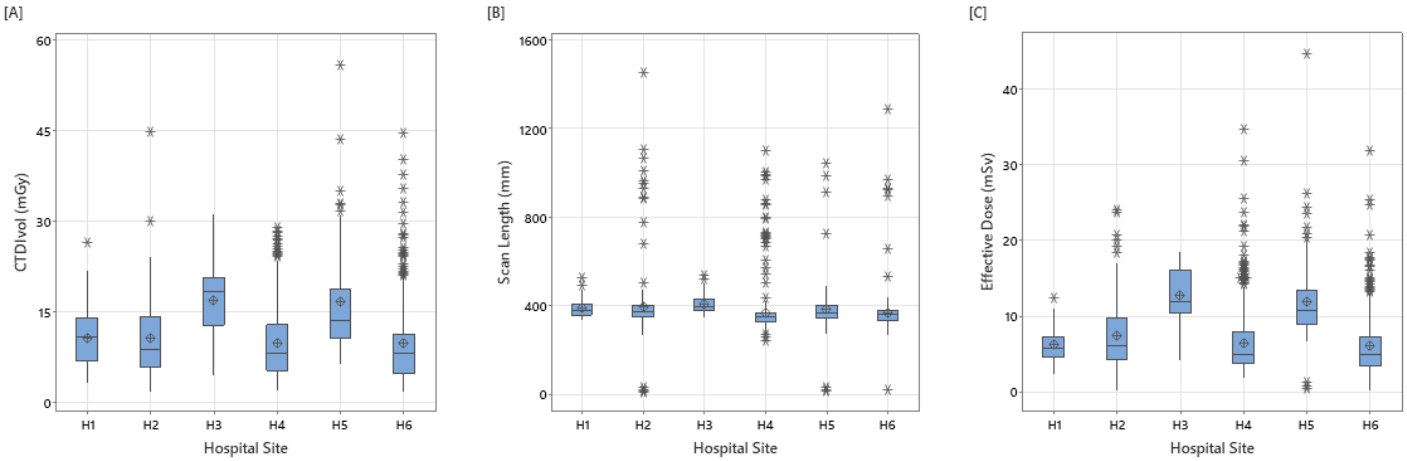


Figure 4.8 [A-C]: Pulmonary angiogram: A. CTDIvol (mGy) B. Scan Length (mm) C. Effective Dose (mSv). Represents the distribution of dose (CTDIvol and effective dose) and technical parameters (scan length) by hospital for PA protocols performed in 2018 for six hospital sites.

CTDIvol: The CTDIvol mean values ranged from 9.62 $\pm$ 6.84 mGy to 16.77 $\pm$ 5.32 mGy (Table A.1). Apart from H3 and H1, all sites contain outliers failing above the mean and mean CTDIvol values are higher than the median. For PA protocol, mean CTDIvol significantly differs between some sites. H3 cf H5, and H1 cf H2 cf H4 cf H6 exhibited similar means.

Scan length: Mean scan lengths for PA protocols ranged from 365.65 $\pm$ 100.17 mm to 405.57 $\pm$ 38.20 mm (Table A.2). Like other protocols, several outliers are present in the dataset above and below the mean. Mean scan lengths do not intersect the median but fall above it for each site. The preponderance of sites shares statistically similar means for PA protocol. Site pairs that exhibited variance in mean scan lengths included H2 cf H4.

ED: effective dose averages ranged from 6.15 $\pm$ 4.21 mSv to 12.76 $\pm$ 3.49 mSv (Table A.3). Figure 4.8-C provides the effective dose for the PA protocol. H1 cf H2 cf H4 cf H5 cf H6 contain outliers above the mean. The mean dose also does not intersect the median for these sites but falls above it. Statistical analysis demonstrates significant variation between mean dose measures between site pairs but hospitals H3 cf H5, H1 cf H2 cf H4, and H1 cf H4 cf H6 exhibit similar means.

4.1.9 Renal Colic (RCOL)

The dataset contained 1,829 exams (RCOL), but these were unevenly distributed over the site. Tukey Pairwise comparison test was selected to measure significant difference in site means. Means that do not share a letter are significantly different ($p < 0.05$) (Table 4.10).

Table 4.10 *Grouping information for renal colic exam variables using the Tukey Method and 95% confidence (2018)*

[A] CTDIvol (mGy)

Hospital Site	Mean	Grouping
H1	7.19	B
H2	8.71	B
H3	14.11	A
H4	8.44	B
H5	13.70	A
H6	7.86	B

[B] Scan Length (mm)

Hospital Site	Mean	Grouping
H1	497.58	C
H2	555.79	A
H3	447.00	D
H4	508.83	C
H5	526.66	B
H6	499.61	C

[C] Effective Dose (mSv)

Hospital Site	Mean	Grouping
H1	5.24	E
H2	6.97	C
H3	9.36	B
H4	6.36	C D
H5	10.74	A
H6	5.88	D E

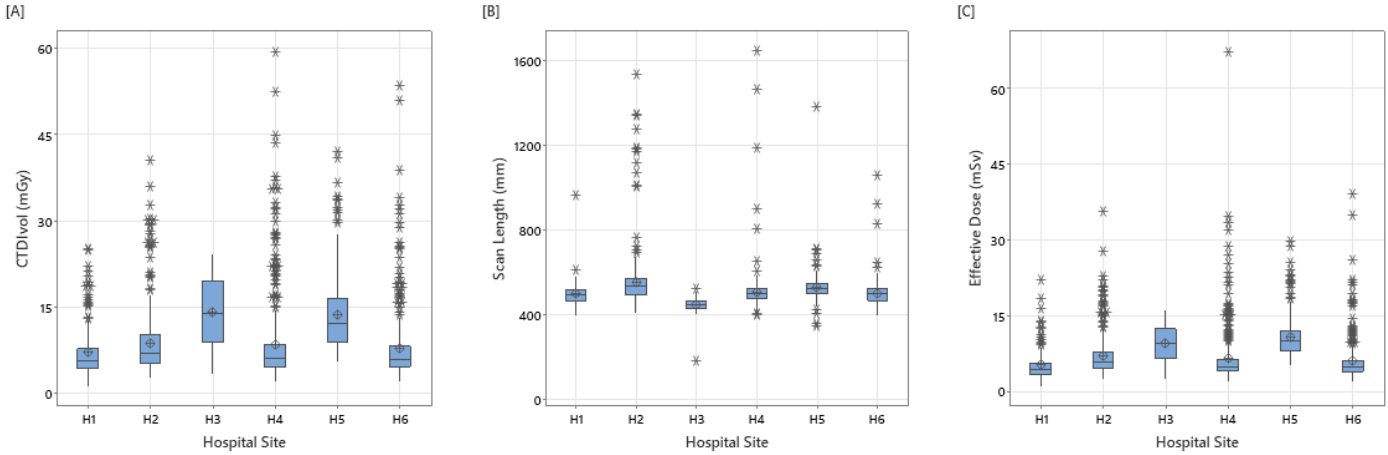


Figure 4.9 [A-C]: Renal colic: A. CTDIvol (mGy) B. Scan Length (mm) C. Effective Dose (mSv). Represents the distribution of dose (CTDIvol and effective dose) and technical parameters (scan length) by hospital for RCOL protocols performed in 2018 for six hospital sites.

CTDIvol: The CTDIvol mean values ranged from 7.19 $\pm$ 4.67 mGy to 14.11 $\pm$ 5.76 mGy (Table A.1). Several outliers fall above the mean for all sites but H3. For the preponderance of sites, mean CTDIvol values do not intersect the median but fall above it. These datasets represent a greater cluster of data in the upper quartiles. For RCOL protocol, mean CTDIvol significantly differs between some sites. H3 cf H5, and H1 cf H2 cf H4 cf H6 exhibited similar means.

Scan length: Mean scan lengths for RCOL ranged from 447.00 ± 33.90 mm to 555.79 ± 127.05 mm (Table A.2). A number of outliers are present in the dataset above and below the mean. Mean scan length observed for RCOL procedures in H1 cf H4 cf H6 were similar, while the other site pairs significantly differed.

ED: Effective dose averages ranged from 5.24 ± 3.11 mSv to 10.74 ± 3.78 mSv (Table A.3). Similar trends observed in CTDIvol can be extended to the effective dose dataset. Statistical analysis reveals that there is marginally more variation in the mean effective dose than CTDIvol. H2 cf H4, H4 cf H6, and H1 cf H6 exhibit similar means, but the remaining pairs significantly differ.

4.1.10 Routine Head without Contrast (RHC-)

The dataset contained 6,045 exams (RHC-), but these were unevenly distributed over the sites. Tukey Pairwise comparison test was selected to measure significant difference in site means. Means that do not share a letter are significantly different ($p < 0.05$) (Table 4.11).

Table 4.11 *Grouping information for routine head without contrast exam variables using the Tukey Method and 95% confidence (2018)*

[A] CTDIvol (mGy)

Hospital Site	Mean	Grouping
H1	54.57	F
H2	58.46	E
H3	63.17	A
H4	60.93	B
H5	60.09	C
H6	59.35	D

[B] Scan Length (mm)

Hospital Site	Mean	Grouping
H1	163.43	C
H2	192.96	A
H3	143.73	D
H4	175.65	B
H5	183.37	A B
H6	192.94	A

[C] Effective Dose (mSv)

Hospital Site	Mean	Grouping
H1	2.28	C
H2	2.78	A
H3	2.39	C
H4	2.63	B
H5	2.76	A
H6	2.77	A

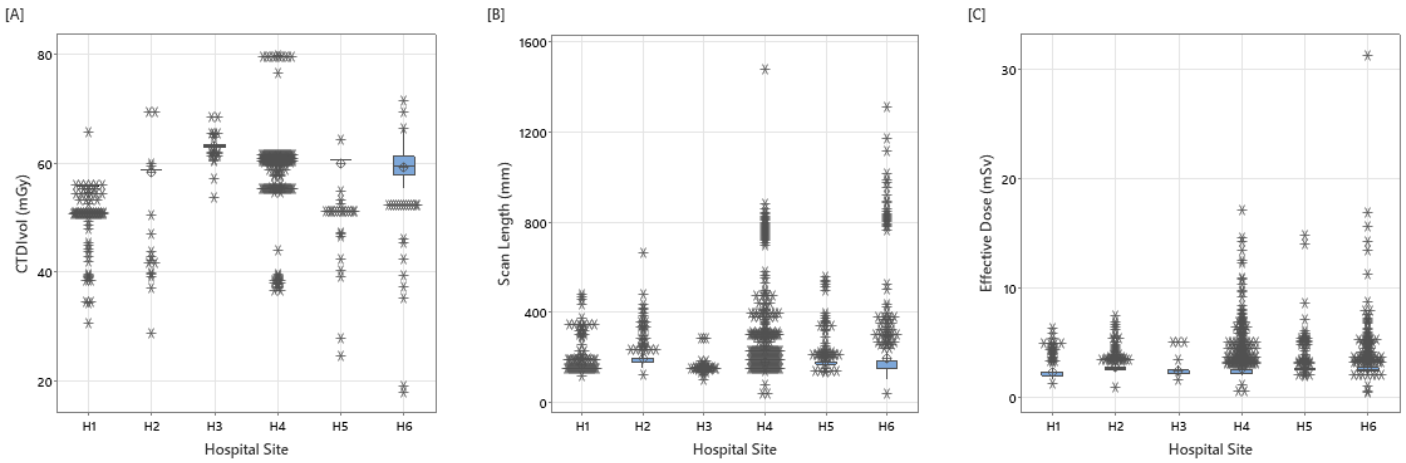


Figure 4.10 [A-C]: Routine head without contrast: A. CTDIvol (mGy) B. Scan Length (mm) C. Effective Dose (mSv). Represents the distribution of dose (CTDIvol and effective dose) and technical parameters (scan length) by hospital for RHC- protocols performed in 2018 for six hospital sites.

CTDIvol: The CTDIvol mean values ranged from 54.57 $\pm$ 3.38 mGy to 63.17 $\pm$ 0.78 mGy (Table A.1-A.18). Unlike the non-head protocols, outliers are present both above and below the mean for RHC- CTDIvol dataset with the preponderance of outliers below the mean. Statistically, mean CTDIvol measures vary between all sites.

Scan length: Scan lengths for RHC- examinations ranged from 143.73 $\pm$ 12.23 mm to 192.96 $\pm$ 42.24 mm (Table A.1). Outliers are present in each dataset, with a higher density above the mean. Mean scan lengths between sites have been proven to be significantly different for the preponderance of sites. H2 cf H5 cf H6, and H4 cf H5 exhibited similar means.

ED: Effective dose averages ranged from 2.28 $\pm$ 0.54 mSv to 2.78 $\pm$ 0.54 mSv (Table A.3). ED dataset for RHC- exhibits outliers above and below the mean with the preponderance falling above the mean. Statistical analysis demonstrates variation between average effective dose

measures for site pairs tested. Site pairs whose means did not differ include H2 cf H5 cf H6, and H1 cf H3.

4.1.11 Routine Head with/without Contrast (RHCC)

The dataset contained 1,478 exams (RHCC), but these were unevenly distributed over the sites. Tukey Pairwise comparison test was selected to measure significant difference in site means. Means that do not share a letter are significantly different ($p < 0.05$) (Table 4.12).

Table 4.12 *Grouping information for routine head with/without contrast exam variables using the Tukey Method and 95% confidence (2018)*

[A] CTDIvol (mGy)

Hospital Site	Mean	Grouping
H1	55.01	F
H2	58.51	E
H3	63.30	A
H4	61.14	B
H5	60.54	C
H6	59.31	D

[B] Scan Length (mm)

Hospital Site	Mean	Grouping
H1	308.35	C
H2	364.37	A
H3	286.60	C
H4	302.14	C
H5	338.96	B
H6	342.85	B

[C] Effective Dose (mSv)

Hospital Site	Mean	Grouping
H1	4.38	D
H2	5.28	A
H3	4.73	C D
H4	4.72	D
H5	5.32	A B
H6	5.08	B C

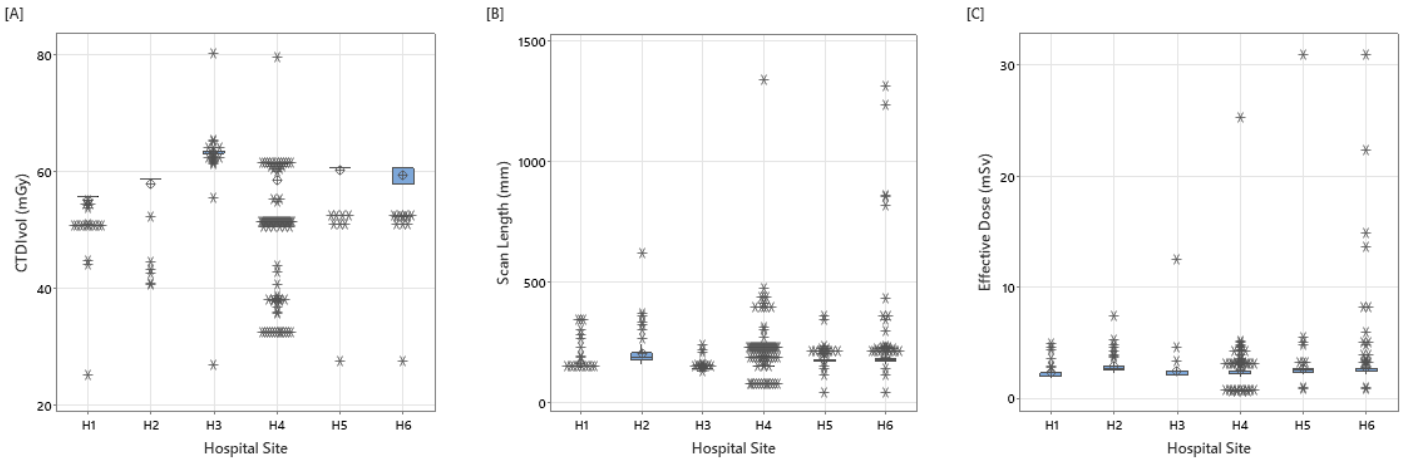


Figure 4.11 [A-C]: Routine head with/without contrast: A. CTDIvol (mGy) B. Scan Length (mm) C. Effective Dose (mSv). Represents the distribution of dose (CTDIvol and effective dose) and

technical parameters (scan length) by hospital for RHCC protocols performed in 2018 for six hospital sites.

CTDIvol: The CTDIvol mean values ranged from 55.01 ± 1.83 mGy to 63.30 ± 0.47 mGy (Table A.1). Outliers are present in the dataset for all sites failing below the mean resulting in a slight clustering of data in the lower quartiles. This trend is unique to head protocols, non-head protocols exhibit outliers above the mean. The CTDIvol means varied between all sites.

Scan length: Scan lengths for RHCC examinations ranged from 286.60 ± 9.02 mm to 364.37 ± 58.74 mm (Table A.2). Mean scan length differed for site pairs but H5 cf H6, and H1 cf H3 cf H4 exhibited similar means. Outliers were present in the dataset, both above and below the mean.

ED: Effective dose averages ranged from 4.38 ± 0.65 mSv to 5.32 ± 1.80 mSv (Table A.3). Apart from H3, outliers are present both above and below the mean. ED means observed for RHCC procedures in H2 cf H5, H5 cf H6, H3 cf H6, and H1 cf H3 cf H4 were similar with the remaining site pairs exhibiting a significant difference.

4.1.12 Routine Head with Contrast (RHC+)

The dataset contained 1,961 exams (RHC+), but these were unevenly distributed over the sites. Tukey Pairwise comparison test was selected to measure significant difference in site means. Means that do not share a letter are significantly different ($p < 0.05$) (Table 4.13).

Table 4.13 *Grouping information for routine head with contrast Exam variables using the Tukey Method and 95% confidence (2018)*

[A] CTDIvol (mGy)

Hospital Site	Mean	Grouping
H1	55.07	E
H2	57.99	D
H3	63.22	A
H4	58.57	D
H5	60.33	B
H6	59.33	C

[B] Scan Length (mm)

Hospital Site	Mean	Grouping
H1	158.26	B C
H2	199.74	A
H3	142.77	C
H4	170.71	B
H5	174.38	B
H6	188.93	A

[C] Effective Dose (mSv)

Hospital Site	Mean	Grouping
H1	2.28	C
H2	2.87	A
H3	2.43	B C
H4	2.57	A B C
H5	2.70	A B
H6	2.81	A

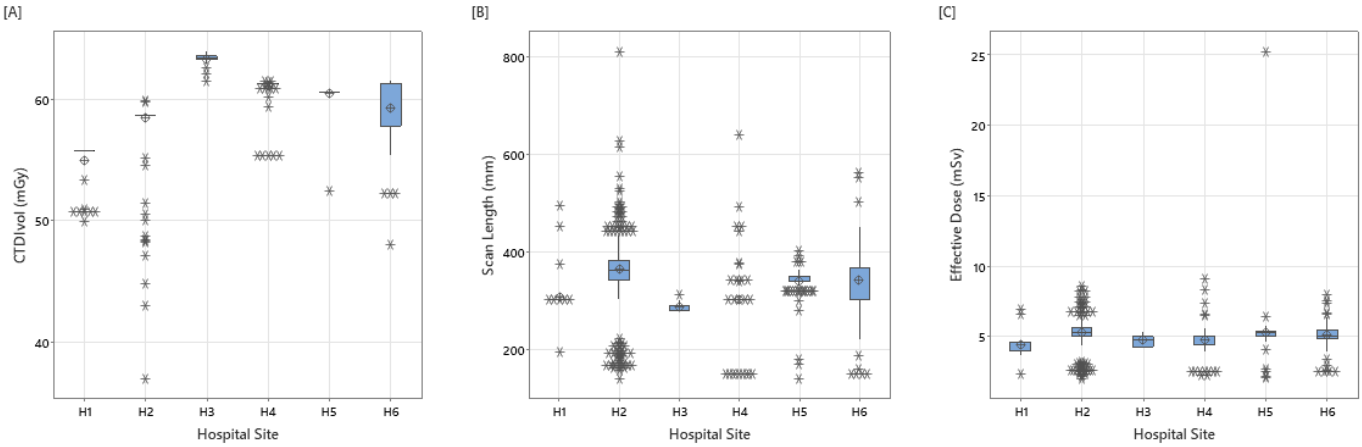


Figure 4.12 [A-C]: Routine head with contrast: A. CTDIvol (mGy) B. Scan Length (mm) C. Effective Dose (mSv). Represents the distribution of dose (CTDIvol and effective dose) and technical parameters (scan length) by hospital for RHC+ protocols performed in 2018 for six hospital sites.

CTDIvol: The CTDIvol mean values ranged from 55.07 $\pm$ 2.96 mGy to 63.22 $\pm$ 2.27 mGy (Table A.1). The dataset exhibits outliers above and below the mean with a greater clustering below the mean. The CTDIvol means varied between the preponderance sites but H2 cf H4 exhibited similar means.

Scan length: Scan lengths for RHC+ examinations ranged from 142.77 ± 8.88 mm to 199.74 ± 52.96 mm (Table A.2). Regarding outliers**,** similar trends are observed in the scan length dataset as were for dose metrics, with marginally more preference for outliers falling above the mean. Statistical analysis demonstrates significant differences in average scan length between each site apart from H2 cf H6, H1 cf H4 cf H5, and H1 cf H3.

ED: Effective dose averages ranged from 2.28 ± 0.39 mSv to 2.87 ± 0.65 mSv (Table A.3). The dataset exhibits outliers above and below the mean. Statistical analysis demonstrates significant variation in average effective dose between sites but H2 cf H4 cf H5 cf H6, H3 cf H4 cf H5, and H1 cf H3 cf H4 exhibit similar means.

4.2 Distribution of Radiation Doses and Exam Scan Lengths (2018-2021)

4.2.1 Abdomen Pelvis without Contrast

Table 4.14 provides a summary of the annual mean CTDIvol, ED, and scan length metrics for 2018-2021 for APC- protocol as well as a statistical grouping summary of variable comparisons within sites. Means that do not share a letter are significantly different ($p < 0.05$). Statistical analysis (Table A.16-A.18) revealed that for most sites, there was no significant difference in dose or scan lengths used in APC- protocol over the four years. H4 was an exception showing a significant difference in scan length over the four years. Additionally, the ED values for APC- monotonically increased from 8.18 ± 6.80 mSv in 2018 to 16.04 ± 11.01 mSv in 2021 for H4. This increase appears to have contributions from CTDI and scan length. Complete descriptive statistics for examined scan parameters are provided in the appendix (Table A.1-A.12).

Table 4.14 *Within site grouping information for abdomen pelvis without contrast exam variables using the Tukey Method and 95% confidence (2018-2021)*

[A] CTDIvol (mGy)

H1			
Year	Mean	Grouping	
2018	9.30		B
2019	9.77	A	B
2020	10.34	A	B
2021	12.16	A	

H2			
Year	Mean	Grouping	
2018	10.62		B
2019	11.68	A	B
2020	12.68	A	
2021	11.09	A	B

H3		
Year	Mean	Grouping
2018	14.44	A
2019	14.66	A
2020	15.56	A
2021	13.07	A

H4			
Year	Mean	Grouping	
2018	10.69		B
2019	11.56		B
2020	18.15	A	
2021	18.54	A	

H5		
Year	Mean	Grouping
2018	15.22	A
2019	14.30	A
2020	13.96	A
2021	15.86	A

H6		
Year	Mean	Grouping
2018	9.66	A
2019	9.67	A
2020	11.00	A
2021	9.70	A

[B] Scan Length (mm)

H1		
Year	Mean	Grouping
2018	513.20	A
2019	509.00	A
2020	527.90	A
2021	500.87	A

H2		
Year	Mean	Grouping
2018	578.64	A
2019	589.90	A
2020	611.00	A
2021	595.40	A

H3		
Year	Mean	Grouping
2018	485.89	A
2019	504.28	A
2020	497.50	A
2021	504.30	A

H4			
Year	Mean	Grouping	
2018	525.82		C
2019	567.70	A B	
2020	538.70	B	C
2021	592.00	A	

H5		
Year	Mean	Grouping
2018	537.33	A
2019	514.12	A
2020	520.50	A
2021	523.30	A

H6		
Year	Mean	Grouping
2018	533.08	A
2019	547.90	A
2020	524.60	A
2021	527.60	A

[C] Effective Dose (mSv)

H1			
Year	Mean	Grouping	
2018	6.95		B
2019	7.27	A	B
2020	7.56	A	B
2021	8.92	A	

H2			
Year	Mean	Grouping	
2018	8.87		B
2019	9.70	A	B
2020	10.51	A	
2021	9.43	A	B

H3			
Year	Mean	Grouping	
2018	10.18		B
2019	11.03	A	B
2020	11.50	A	
2021	10.10	A	B

H4			
Year	Mean	Grouping	
2018	8.19		B
2019	9.84		B
2020	14.62	A	
2021	16.04	A	

H5		
Year	Mean	Grouping
2018	11.91	A
2019	10.91	A
2020	10.84	A
2021	11.91	A

H6		
Year	Mean	Grouping
2018	7.59	A
2019	8.15	A
2020	8.35	A
2021	7.72	A

4.2.2 Abdomen Pelvis with Contrast

Table 4.15 provides a summary of the annual mean CTDIvol, ED, and scan length metrics for 2018- 2021 for APC+ protocol as well as a statistical grouping summary of variable comparisons within sites. Means that do not share a letter are significantly different ($p < 0.05$). Statistical analysis (Table A.19-A.21) revealed that for most sites, there was no significant difference in dose or scan length used in APC+ protocol over the four years. Similar to the results from APC- protocol, H4 was an exception showing a significant difference in dose and scan length over the four years. The ED values for APC+ monotonically increase from 9.46 ± 6.69 mSv in 2018 to 13.85 ± 7.98 mSv in 2021 for H4. This increase appears to have contributions from CTDI and scan length. Complete descriptive statistics for examined scan parameters are provided in the appendix (Table A.1-A.12).

Table 4.15 *Within site grouping information for abdomen pelvis with contrast exam variables using the Tukey Method and 95% confidence (2018-2021)*

[A] CTDIvol (mGy)

H1		
Year	Mean	Grouping
2018	9.84	A
2019	9.69	A
2020	9.83	A
2021	10.24	A

H2		
Year	Mean	Grouping
2018	10.78	A
2019	10.89	A
2020	10.92	A
2021	10.48	A

H3		
Year	Mean	Grouping
2018	14.49	B
2019	14.18	B
2020	16.33	A
2021	13.98	B

[B] Scan Length (mm)

H1			
Year	Mean	Grouping	
2018	501.90	A	B
2019	498.77		B
2020	513.27	A	B
2021	516.08	A	

H2			
Year	Mean	Grouping	
2018	554.76		B
2019	556.05		B
2020	553.49		B
2021	564.63	A	

H3			
Year	Mean	Grouping	
2018	521.63	A	
2019	511.10	A	
2020	411.34		B
2021	513.58	A	

[C] Effective Dose (mSv)

H1		
Year	Mean	Grouping
2018	10.60	A
2019	10.45	A
2020	10.91	A
2021	11.46	A

H2		
Year	Mean	Grouping
2018	8.78	A
2019	8.88	A
2020	8.88	A
2021	8.71	A

H3		
Year	Mean	Grouping
2018	11.47	A
2019	11.10	A
2020	9.05	B
2021	10.91	A

Table 4.15 *(continued)*

H4		
Year	Mean	Grouping
2018	12.07	C
2019	12.05	C
2020	16.33	B
2021	17.37	A

H4		
Year	Mean	Grouping
2018	519.61	B C
2019	514.81	C
2020	526.92	A B
2021	531.20	A

H4		
Year	Mean	Grouping
2018	9.46	C
2019	9.35	C
2020	12.99	B
2021	13.85	A

H5		
Year	Mean	Grouping
2018	14.09	B
2019	14.72	A B
2020	14.64	A B
2021	15.02	A

H5		
Year	Mean	Grouping
2018	534.05	A
2019	525.47	A B
2020	519.68	B C
2021	509.41	C

H5		
Year	Mean	Grouping
2018	11.40	A
2019	11.53	A
2020	11.31	A
2021	11.44	A

H6		
Year	Mean	Grouping
2018	11.76	A
2019	12.21	A
2020	11.86	A
2021	11.81	A

H6		
Year	Mean	Grouping
2018	505.24	B
2019	524.52	A
2020	526.67	A
2021	529.83	A

H6		
Year	Mean	Grouping
2018	8.84	B
2019	9.54	A
2020	9.29	A B
2021	9.28	A B

4.2.3 Chest Abdomen Pelvis without Contrast

Table 4.16 provides a summary of the annual mean CTDIvol, ED, and scan length metrics for 2018-2021 for CAPC- protocol as well as a statistical grouping summary of variable comparisons within sites. Means that do not share a letter are significantly different ($p < 0.05$). Mean exam metrics compared within hospitals remained relatively consistent over the observation period (Table 4.16). The ED values for CAPC- monotonically increased from 9.67 ± 5.34 mSv in 2018 to 16.51 ± 9.82 mSv in 2021 for H4. Full descriptive statistics for examined exam variables are provided in the appendix (Table A.1-A.12).

Table 4.16 *Within site grouping information for chest abdomen pelvis without contrast exam variables using the Tukey Method and 95% confidence (2018-2021)*

[A] CTDIvol (mGy)

H1		
Year	Mean	Grouping
2018	7.56	A
2019	8.14	A
2020	8.10	A
2021	8.54	A

H2		
Year	Mean	Grouping
2018	9.19	A
2019	9.71	A
2020	9.42	A
2021	9.69	A

H3		
Year	Mean	Grouping
2018	11.60	A
2019	14.33	A
2020	12.39	A
2021	14.83	A

H4		
Year	Mean	Grouping
2018	10.07	B
2019	9.87	B
2020	13.96	A
2021	12.88	A

H5		
Year	Mean	Grouping
2018	10.18	A
2019	9.58	A
2020	10.10	A
2021	10.40	A

H6		
Year	Mean	Grouping
2018	9.29	A
2019	7.89	A
2020	9.22	A
2021	9.11	A

[B] Scan Length (mm)

H1		
Year	Mean	Grouping
2018	687.39	A
2019	692.94	A
2020	683.40	A
2021	699.52	A

H2		
Year	Mean	Grouping
2018	741.50	B
2019	768.50	B
2020	717.80	B
2021	886.50	A

H3		
Year	Mean	Grouping
2018	839.79	A
2019	834.65	A
2020	674.10	B
2021	857.10	A

H4		
Year	Mean	Grouping
2018	706.15	B
2019	748.70	B
2020	706.60	B
2021	840.62	A

H5		
Year	Mean	Grouping
2018	864.39	A
2019	695.64	B
2020	668.20	B
2021	685.63	B

H6		
Year	Mean	Grouping
2018	659.70	B
2019	678.70	B
2020	653.00	B
2021	860.72	A

[C] Effective Dose (mSv)

H1		
Year	Mean	Grouping
2018	7.87	A
2019	8.28	A
2020	8.38	A
2021	8.58	A

H2		
Year	Mean	Grouping
2018	9.82	B
2019	10.45	B
2020	9.69	B
2021	11.95	A

H3		
Year	Mean	Grouping
2018	16.25	A B
2019	18.17	A
2020	14.69	B
2021	17.83	A B

H4		
Year	Mean	Grouping
2018	9.67	B
2019	10.75	B
2020	14.98	A
2021	16.51	A

H5		
Year	Mean	Grouping
2018	14.00	A
2019	9.76	B
2020	10.37	B
2021	10.72	B

H6		
Year	Mean	Grouping
2018	8.86	B
2019	7.67	B
2020	9.21	B
2021	11.69	A

4.2.4 Chest Abdomen Pelvis with Contrast

Table 4.17 provides a summary of the annual mean CTDIvol, ED, and scan length metrics for 2018-2021 for CAPC+ protocol as well as a statistical grouping summary of variable comparisons within sites. Means that do not share a letter are significantly different ($p < 0.05$). See Table A.1-A.12 for complete descriptive statistics. A comparison within sites demonstrated that the preponderance of sites exhibited no significant difference in reported dose metrics. However, H4 displayed significant institutional differences in reported CTDIvol, H5 cf H6 displayed institutional differences in scan length, and H3 cf H4 exhibited institutional differences in ED.

Table 4.17 *Within site grouping information for chest abdomen pelvis with contrast exam variables using the Tukey Method and 95% confidence (2018-2021)*

[A] CTDIvol (mGy)

H1 Year	Mean	Grouping
2018	7.20	A
2019	6.89	A
2020	6.64	A
2021	6.87	A

H2 Year	Mean	Grouping
2018	9.20	B
2019	8.98	B
2020	9.43	A B
2021	9.86	A

H3 Year	Mean	Grouping
2018	12.92	A
2019	12.91	A
2020	12.94	A
2021	12.67	A

[B] Scan Length (mm)

H1 Year	Mean	Grouping
2018	899.01	A
2019	900.16	A
2020	666.00	B
2021	922.58	A

H2 Year	Mean	Grouping
2018	931.76	B
2019	926.32	B
2020	695.21	B
2021	951.41	A

H3 Year	Mean	Grouping
2018	855.31	A
2019	848.83	A
2020	655.47	B
2021	856.62	A

[C] Effective Dose (mSv)

H1 Year	Mean	Grouping
2018	9.58	A
2019	9.52	A
2020	7.44	B
2021	9.72	A

H2 Year	Mean	Grouping
2018	12.82	B
2019	12.63	B
2020	9.75	B
2021	13.29	A

H3 Year	Mean	Grouping
2018	17.48	A B
2019	17.33	B
2020	13.63	C
2021	16.87	A

Table 4.17 *(continued)*

H4			
Year	Mean	Grouping	
2018	8.86		C
2019	8.06		C
2020	10.72	B	
2021	11.91	A	

H5			
Year	Mean	Grouping	
2018	11.00	A	
2019	11.31	A	
2020	11.27	A	
2021	11.31	A	

H6			
Year	Mean	Grouping	
2018	9.02	A	B
2019	9.60	A	
2020	8.81		B
2021	9.18	A	B

H4			
Year	Mean	Grouping	
2018	886.31	A	
2019	869.58	A	
2020	677.87		B
2021	883.49	A	

H5			
Year	Mean	Grouping	
2018	878.92	A	
2019	868.07	A	B
2020	643.48		C
2021	853.42		B

H6			
Year	Mean	Grouping	
2018	871.78		B
2019	901.62	A	
2020	682.07		C
2021	894.86	A	

H4			
Year	Mean	Grouping	
2018	12.15		B
2019	10.88		C
2020	11.97		B
2021	16.32	A	

H5			
Year	Mean	Grouping	
2018	15.17	A	
2019	15.41	A	
2020	12.23		B
2021	15.33	A	

H6			
Year	Mean	Grouping	
2018	12.05	A	
2019	12.78	A	
2020	9.63		B
2021	12.37	A	

4.2.5 Chest without Contrast

Table 4.18 provides a summary of the annual mean CTDIvol, ED, and scan length metrics for 2018-2021 for CC- protocol as well as a statistical grouping summary of variable comparisons within sites. Means that do not share a letter are significantly different ($p < 0.05$). Statistical analysis (Table A.27-A.29) revealed that for most of the sites, there was no significant difference in dose or scan length used in CC- protocol over the four years. ED values for CC- protocol monotonically increased form 2.95 ± 1.85 mSv in 2019 to 4.93 ± 4.65 mSv in 2021 for H4. Complete descriptive statistics for examined scan parameters are provided in the appendix (Table A.1-A.12).

Table 4.18 *Within site grouping information for chest without contrast exam variables using the Tukey Method and 95% confidence (2018-2021)*

[A] CTDIvol (mGy)

H1		
Year	Mean	Grouping
2018	4.27	A
2019	3.96	A
2020	4.60	A
2021	4.65	A

H2		
Year	Mean	Grouping
2018	8.61	B
2019	9.18	A B
2020	9.41	A B
2021	9.78	A

H3		
Year	Mean	Grouping
2018	12.33	A
2019	12.63	A
2020	12.59	A
2021	11.79	A

H4		
Year	Mean	Grouping
2018	4.80	B
2019	4.57	B
2020	6.81	A
2021	7.08	A

H5		
Year	Mean	Grouping
2018	9.55	A
2019	10.01	A
2020	9.74	A
2021	9.58	A

H6		
Year	Mean	Grouping
2018	7.45	A
2019	7.46	A
2020	7.46	A
2021	7.41	A

[B] Scan Length (mm)

H1		
Year	Mean	Grouping
2018	433.28	A
2019	426.19	A
2020	430.42	A
2021	426.60	A

H2		
Year	Mean	Grouping
2018	415.58	A
2019	414.01	A
2020	413.57	A
2021	413.20	A

H3		
Year	Mean	Grouping
2018	360.44	B
2019	358.98	B
2020	390.00	A
2021	365.20	B

H4		
Year	Mean	Grouping
2018	410.01	A
2019	375.75	B
2020	408.60	A
2021	394.77	A B

H5		
Year	Mean	Grouping
2018	384.23	A
2019	392.04	A
2020	392.81	A
2021	392.49	A

H6		
Year	Mean	Grouping
2018	395.19	A B
2019	405.23	A
2020	383.89	B
2021	399.86	A B

[C] Effective Dose (mSv)

H1		
Year	Mean	Grouping
2018	3.19	A
2019	2.91	A
2020	3.28	A
2021	3.27	A

H2		
Year	Mean	Grouping
2018	6.01	A
2019	6.36	A
2020	6.01	A
2021	6.51	A

H3		
Year	Mean	Grouping
2018	8.20	A
2019	8.10	A B
2020	8.18	A B
2021	7.65	B

H4		
Year	Mean	Grouping
2018	3.50	B
2019	2.95	B
2020	4.41	A
2021	4.93	A

H5		
Year	Mean	Grouping
2018	6.21	B
2019	6.51	A
2020	6.13	B
2021	6.23	A B

H6		
Year	Mean	Grouping
2018	5.10	A
2019	5.16	A
2020	4.90	A
2021	5.23	A

4.2.6 Chest with Contrast

Table 4.19 provides a summary of the annual mean CTDIvol, ED, and scan length metrics for 2018-2021 for CC+ protocol as well as a statistical grouping summary of variable comparisons

within sites. Means that do not share a letter are significantly different ($p < 0.05$). Dose and scan length values for this protocol at each site remained relatively similar over the observation period. H4 was an exception showing a significant difference in CTDI and ED over the four years. Additionally, the ED values for APC- monotonically increased from 2.39 ± 1.31 mSv in 2019 to 3.90 ± 1.88 mSv in 2021 for H4. For most of the sites, scan length exhibits the greatest significant difference over four years. Complete descriptive statistics for examined scan parameters are provided in the appendix (Table A.1-A.12).

Table 4.19 *Within site grouping information for chest with contrast exam variables using the Tukey method and 95% confidence (2018-2021)*

[A] CTDIvol (mGy)

H1		
Year	Mean	Grouping
2018	3.92	A
2019	4.00	A
2020	3.80	A
2021	3.87	A

H2		
Year	Mean	Grouping
2018	9.26	A
2019	9.32	A
2020	8.90	A
2021	9.28	A

H3		
Year	Mean	Grouping
2018	11.99	A
2019	12.73	A
2020	12.32	A
2021	11.71	A

H4		
Year	Mean	Grouping
2018	4.28	C
2019	4.13	C
2020	5.77	B
2021	6.47	A

[B] Scan Length (mm)

H1		
Year	Mean	Grouping
2018	411.40	B
2019	420.47	B
2020	458.80	A
2021	430.04	B

H2		
Year	Mean	Grouping
2018	404.33	A B
2019	396.34	B
2020	415.80	A
2021	405.79	A B

H3		
Year	Mean	Grouping
2018	359.42	B
2019	359.71	B
2020	371.62	A
2021	366.81	A B

H4		
Year	Mean	Grouping
2018	378.70	A B
2019	370.63	B
2020	392.14	A
2021	385.14	A B

[C] Effective Dose (mSv)

H1		
Year	Mean	Grouping
2018	2.35	A
2019	2.44	A
2020	2.39	A
2021	2.42	A

H2		
Year	Mean	Grouping
2018	6.26	A
2019	6.21	A
2020	6.04	A
2021	6.16	A

H3		
Year	Mean	Grouping
2018	7.89	A B
2019	8.25	A
2020	7.96	A B
2021	7.60	B

H4		
Year	Mean	Grouping
2018	2.57	C
2019	2.39	C
2020	3.48	B
2021	3.90	A

Table 4.19 *(continued)*

H5 Year	Mean	Grouping
2018	9.65	A
2019	9.78	A
2020	9.84	A
2021	9.51	A

H5 Year	Mean	Grouping
2018	369.20	A
2019	358.20	A
2020	375.96	A
2021	362.10	A

H5 Year	Mean	Grouping
2018	6.25	A
2019	6.15	A
2020	6.18	A
2021	6.08	A

H6 Year	Mean	Grouping
2018	7.43	A
2019	7.48	A
2020	7.27	A
2021	7.33	A

H6 Year	Mean	Grouping
2018	385.06	B
2019	391.52	B
2020	411.22	A
2021	387.61	B

H6 Year	Mean	Grouping
2018	4.56	A
2019	4.62	A
2020	4.42	A
2021	4.42	A

4.2.7 Lumbar Spine

Table 4.20 provides a summary of the annual mean CTDIvol, ED, and scan length metrics for 2018-2021 for LS protocol as well as a statistical grouping summary of variable comparisons within sites. Means that do not share a letter are significantly different ($p < 0.05$). Within-site analysis (Table A.33-A.35) determined that for most sites there was no significant difference in dose or scan length used in LS protocol over the four years. Similar to other protocols mean ED for LS protocol monotonically increased form 16.53 ± 10.16 mSv in 2018 to 23.40 ± 11.91 mSv in 2021 for H4. Complete descriptive statistics for examined scan parameters are provided in the appendix (Table A.1-A.12).

Table 4.20 *Within site grouping information for lumbar spine exam variables using the Tukey Method and 95% confidence (2018-2021)*

[A] CTDIvol (mGy)

H1 Year	Mean	Grouping	
2018	30.26	A	
2019	26.47		B
2020	30.11	A	
2021	28.84	A	B

[B] Scan Length (mm)

H1 Year	Mean	Grouping
2018	245.86	B
2019	239.76	B
2020	273.26	A
2021	248.96	B

[C] Effective Dose (mSv)

H1 Year	Mean	Grouping	
2018	18.97	A	
2019	16.03		B
2020	18.94	A	
2021	18.15	A	

Table 4.20 *(continued)*

H2		
Year	Mean	Grouping
2018	30.97	A
2019	32.38	A
2020	33.17	A
2021	32.96	A

H2		
Year	Mean	Grouping
2018	224.12	B
2019	230.63	A B
2020	241.57	A
2021	237.58	A

H2		
Year	Mean	Grouping
2018	17.86	B
2019	19.11	A B
2020	19.64	A
2021	19.79	A

H3		
Year	Mean	Grouping
2018	24.26	A
2019	24.27	A
2020	23.84	A
2021	23.67	A

H3		
Year	Mean	Grouping
2018	255.86	A B
2019	248.70	B
2020	259.03	A
2021	252.64	A B

H3		
Year	Mean	Grouping
2018	15.48	A
2019	15.21	A
2020	15.00	A
2021	14.97	A

H4		
Year	Mean	Grouping
2018	30.85	B
2019	30.51	B
2020	42.98	A
2021	43.73	A

H4		
Year	Mean	Grouping
2018	216.69	A B
2019	211.03	B
2020	223.52	A
2021	206.91	B

H4		
Year	Mean	Grouping
2018	16.53	B
2019	16.60	B
2020	23.34	A
2021	23.40	A

H5		
Year	Mean	Grouping
2018	38.04	A
2019	37.63	A
2020	30.83	B
2021	29.62	B

H5		
Year	Mean	Grouping
2018	251.05	A
2019	248.20	A
2020	251.94	A
2021	250.83	A

H5		
Year	Mean	Grouping
2018	23.56	A
2019	22.96	A
2020	18.72	B
2021	18.55	B

H6		
Year	Mean	Grouping
2018	30.28	B
2019	34.89	A
2020	35.26	A
2021	34.17	A

H6		
Year	Mean	Grouping
2018	253.39	A B
2019	245.24	B
2020	265.72	A
2021	261.55	A

H6		
Year	Mean	Grouping
2018	19.07	B
2019	21.14	A
2020	21.78	A
2021	21.54	A

4.2.8 Pulmonary Angiogram

Table 4.21 provides a summary of the annual mean CTDIvol, ED, and scan length metrics for 2018-2021 for PA protocol as well as a statistical grouping summary of variable comparisons within sites. Means that do not share a letter are significantly different ($p < 0.05$). A within-site analysis demonstrated that most sites did not significantly differ in dose or scan length over the four years. The performance of sites displayed exhibited significant differences in scan metrics

for the year 2020. Additionally, mean ED for PA monotonically increased form 6.47 ± 4.18 mSv in 2018 to 10.97 ± 5.34 mSv in 2021 for H4, a similar trend observed in other protocols. Complete descriptive statistics for examined scan parameters are provided in the appendix (Table A.1-A.12).

Table 4.21 *Within site grouping information for pulmonary angiogram exam variables using the Tukey Method and 95% confidence (2018-2021)*

[A] CTDIvol (mGy)

H1 Year	Mean	Grouping
2018	10.56	B
2019	8.63	B
2020	23.83	A
2021	8.24	B

H2 Year	Mean	Grouping
2018	10.46	B
2019	11.52	B
2020	31.37	A
2021	11.64	B

H3 Year	Mean	Grouping
2018	16.77	A
2019	15.88	A B
2020	13.64	B
2021	15.30	A B

H4 Year	Mean	Grouping
2018	9.74	B
2019	10.21	B
2020	33.65	A
2021	15.60	B

H5 Year	Mean	Grouping
2018	16.60	A B
2019	16.39	A B
2020	13.55	B
2021	20.16	A

[B] Scan Length (mm)

H1 Year	Mean	Grouping
2018	388.69	A
2019	357.10	A
2020	230.70	B
2021	387.40	A

H2 Year	Mean	Grouping
2018	393.90	A
2019	354.15	A
2020	273.20	B
2021	378.63	A

H3 Year	Mean	Grouping
2018	405.57	A
2019	404.85	A
2020	253.60	B
2021	408.42	A

H4 Year	Mean	Grouping
2018	365.65	A
2019	352.47	A
2020	255.06	B
2021	370.43	A

H5 Year	Mean	Grouping
2018	380.50	A
2019	445.80	A
2020	262.00	B
2021	454.30	A

[C] Effective Dose (mSv)

H1 Year	Mean	Grouping
2018	6.17	A
2019	5.04	A
2020	3.18	B
2021	5.53	A

H2 Year	Mean	Grouping
2018	7.43	A
2019	6.96	A
2020	4.84	B
2021	7.45	A

H3 Year	Mean	Grouping
2018	12.76	A
2019	12.36	A
2020	7.33	B
2021	12.00	A

H4 Year	Mean	Grouping
2018	6.47	B
2019	6.48	B
2020	7.11	B
2021	10.97	A

H5 Year	Mean	Grouping
2018	11.84	B
2019	12.48	A B
2020	7.26	C
2021	15.31	A

Table 4.21 *(continued)*

H6		
Year	Mean	Grouping
2018	9.62	B
2019	11.00	B
2020	20.68	A
2021	10.22	B

H6		
Year	Mean	Grouping
2018	366.56	A
2019	381.47	A
2020	244.73	B
2021	382.47	A

H6		
Year	Mean	Grouping
2018	6.15	B
2019	7.12	A
2020	4.32	C
2021	6.87	A B

4.2.9 Renal Colic

Table 4.22 provides a summary of the annual mean CTDIvol, ED, and scan length metrics for 2018-2021 for abdomen pelvis without contrast protocol as well as a statistical grouping summary of variable comparisons within sites. Means that do not share a letter are significantly different ($p < 0.05$). Statistical analysis proved ED, CTDIvol, and scan length were largely similar for within-site comparisons of annual mean values. Complete descriptive statistics for examined scan parameters are provided in the appendix (Table A.1-A.12).

Table 4.22 *Within site grouping information for renal colic exam variables using the Tukey Method and 95% confidence (2018-2021)*

[A] CTDIvol (mGy)

H1		
Year	Mean	Grouping
2018	7.19	A
2019	7.81	A
2020	7.82	A
2021	7.37	A

H2		
Year	Mean	Grouping
2018	8.71	A
2019	8.77	A
2020	9.03	A
2021	9.09	A

H3		
Year	Mean	Grouping
2018	14.11	A
2019	14.09	A
2020	14.05	A
2021	14.94	A

[B] Scan Length (mm)

H1		
Year	Mean	Grouping
2018	497.58	A
2019	490.20	A
2020	508.91	A
2021	501.44	A

H2		
Year	Mean	Grouping
2018	555.79	A
2019	551.81	A
2020	558.42	A
2021	561.21	A

H3		
Year	Mean	Grouping
2018	447.00	A
2019	444.93	A
2020	443.01	A
2021	443.64	A

[C] Effective Dose (mSv)

H1		
Year	Mean	Grouping
2018	5.24	A
2019	5.44	A
2020	5.56	A
2021	5.27	A

H2		
Year	Mean	Grouping
2018	6.97	A
2019	7.08	A
2020	7.10	A
2021	7.16	A

H3		
Year	Mean	Grouping
2018	9.36	A
2019	9.38	A
2020	9.24	A
2021	9.71	A

Table 4.22 *(continued)*

H4		
Year	Mean	Grouping
2018	8.44	B
2019	8.95	B
2020	11.98	A
2021	9.85	A

H4		
Year	Mean	Grouping
2018	508.83	A
2019	507.89	A
2020	496.67	A
2021	533.60	A

H4		
Year	Mean	Grouping
2018	6.36	B
2019	6.74	B
2020	9.07	A
2021	8.00	A B

H5		
Year	Mean	Grouping
2018	13.70	A
2019	14.25	A
2020	13.97	A
2021	15.00	A

H5		
Year	Mean	Grouping
2018	526.66	A
2019	523.64	A
2020	522.40	A
2021	528.70	A

H5		
Year	Mean	Grouping
2018	10.74	A
2019	11.01	A
2020	10.89	A
2021	11.46	A

H6		
Year	Mean	Grouping
2018	7.86	A
2019	8.70	A
2020	8.80	A
2021	8.27	A

H6		
Year	Mean	Grouping
2018	499.61	B
2019	523.57	A
2020	511.13	A B
2021	521.05	A

H6		
Year	Mean	Grouping
2018	5.88	A
2019	6.63	A
2020	6.63	A
2021	6.34	A

4.2.10 Routine Head without Contrast

Table 4.23 provides a summary of the annual mean CTDIvol, ED, and scan length metrics for 2018-2021 for abdomen pelvis without contrast protocol as well as a statistical grouping summary of variable comparisons within sites. Means that do not share a letter are significantly different ($p < 0.05$). A within-site comparative analysis showed significant differences in dose and scan length for some sites. Sites that exhibited significant institutional differences in exam variables include H3 (effective dose), H4 (effective dose), H5 (scan length and effective dose), and H6 (CTDIvol). Complete descriptive statistics for examined scan parameters are provided in the appendix (Table A.1-A.12).

Table 4.23 *Within site grouping information for routine head without contrast exam variables using the Tukey Method and 95% confidence (2018-2021)*

[A] CTDIvol (mGy)

H1				
Year	Mean	Grouping		
2018	54.57	A		B
2019	54.96	A		
2020	54.13			B
2021	54.55	A		B

H2				
Year	Mean	Grouping		
2018	58.46	A		B
2019	58.52	A		
2020	58.06			B
2021	58.47	A		B

H3				
Year	Mean	Grouping		
2018	63.17			B
2019	63.20			B
2020	66.39	A		
2021	63.36			B

H4				
Year	Mean	Grouping		
2018	60.93	A		
2019	60.74	A		
2020	60.83	A		
2021	61.00	A		

H5				
Year	Mean	Grouping		
2018	60.09			B
2019	60.55	A		
2020	60.52	A		
2021	60.32	A		B

H6				
Year	Mean	Grouping		
2018	59.35			C
2019	61.12	A		
2020	60.95	A	B	
2021	60.65		B	

[B] Scan Length (mm)

H1				
Year	Mean	Grouping		
2018	163.43			B
2019	163.10			B
2020	203.24	A		
2021	160.09			B

H2				
Year	Mean	Grouping		
2018	192.96			B
2019	193.96			B
2020	218.74	A		
2021	196.38			B

H3				
Year	Mean	Grouping		
2018	143.73	A		
2019	146.61	A		
2020	139.57	A		
2021	149.58	A		

H4				
Year	Mean	Grouping		
2018	175.65			B
2019	177.20			B
2020	209.83	A		
2021	178.27			B

H5				
Year	Mean	Grouping		
2018	183.37	A		
2019	142.16			C
2020	163.19		B	
2021	160.29		B	

H6				
Year	Mean	Grouping		
2018	192.94			B
2019	192.38			B
2020	214.50	A		
2021	202.68	A		B

[C] Effective Dose (mSv)

H1				
Year	Mean	Grouping		
2018	2.28		A	
2019	2.30		A	
2020	2.23		A	
2021	2.30		A	

H2				
Year	Mean	Grouping		
2018	2.78		A	
2019	2.79		A	
2020	2.68			B
2021	2.79		A	

H3				
Year	Mean	Grouping		
2018	2.39		B	
2019	2.44		B	
2020	1.94			C
2021	2.60	A		

H4				
Year	Mean	Grouping		
2018	2.63	A	B	
2019	2.61		B	C
2020	2.54			C
2021	2.71	A		

H5				
Year	Mean	Grouping		
2018	2.76	A		
2019	2.26			C
2020	2.23			C
2021	2.51		B	

H6				
Year	Mean	Grouping		
2018	2.77		A	B
2019	2.71		A	B
2020	2.66			B
2021	2.84		A	

4.2.11 Routine Head with Contrast

Table 4.24 provides a summary of the annual mean CTDIvol, ED, and scan length metrics for 2018-2021 for RHC+ protocol as well as a statistical grouping summary of variable comparisons within sites. Means that do not share a letter are significantly different ($p < 0.05$). Statistical analysis (Table A.45-A.47) revealed that for most sites, there was no significant difference in dose or scan length used in RHC- protocol over the four years. However, H3 exhibited institutional differences in mean ED and H6 exhibited institutional differences in mean CTDIvol. Complete descriptive statistics for examined scan parameters are provided in the appendix (Table A.1-A.12).

Table 4.24 *Within site grouping information for routine head with contrast exam variables using the Tukey Method and 95% confidence (2018-2021)*

[A] CTDIvol (mGy)

H1 Year	Mean	Grouping	
2018	55.07	A	
2019	55.03	A	
2020	54.06		B
2021	54.92	A	B

H2 Year	Mean	Grouping
2018	57.99	A
2019	58.43	A
2020	58.36	A
2021	58.52	A

H3 Year	Mean	Grouping	
2018	63.22		B
2019	63.32		B
2020	65.97	A	
2021	63.25		B

[B] Scan Length (mm)

H1 Year	Mean	Grouping	
2018	158.26		B
2019	156.36		B
2020	196.80	A	
2021	157.57		B

H2 Year	Mean	Grouping	
2018	199.74	A	B
2019	187.17		B
2020	226.00	A	
2021	188.52		B

H3 Year	Mean	Grouping	
2018	142.77	A	B
2019	142.77	A	B
2020	130.89		B
2021	146.17	A	

[C] Effective Dose (mSv)

H1 Year	Mean	Grouping
2018	2.28	A
2019	2.25	A
2020	2.23	A
2021	2.24	A

H2 Year	Mean	Grouping
2018	2.87	A
2019	2.71	A
2020	2.74	A
2021	2.79	A

H3 Year	Mean	Grouping	
2018	2.43		B
2019	2.43		B
2020	2.00		C
2021	2.58	A	

Table 4.24 *(continued)*

H4		
Year	Mean	Grouping
2018	58.57	A
2019	58.29	A
2020	57.57	A
2021	58.29	A

H4		
Year	Mean	Grouping
2018	170.71	A
2019	172.63	A
2020	187.29	A
2021	192.15	A

H4		
Year	Mean	Grouping
2018	2.57	B
2019	2.54	B
2020	2.48	B
2021	2.91	A

H5			
Year	Mean	Grouping	
2018	60.33		B
2019	60.60	A	
2020	60.52	A	B
2021	60.60	A	

H5			
Year	Mean	Grouping	
2018	174.38	A	
2019	141.77		B
2020	173.01	A	
2021	140.52		B

H5			
Year	Mean	Grouping	
2018	2.70	A	
2019	2.27		B
2020	2.25		B
2021	2.25		B

H6			
Year	Mean	Grouping	
2018	59.33		C
2019	61.07	A	
2020	60.86	A	
2021	60.34	B	

H6			
Year	Mean	Grouping	
2018	188.93		B
2019	218.90	A	B
2020	217.24	A	B
2021	233.30	A	

H6			
Year	Mean	Grouping	
2018	2.81		B
2019	3.10	A	B
2020	2.94	A	B
2021	3.31	A	

4.2.12 Routine Head with/without Contrast

Table 4.25 provides a summary of the annual mean CTDIvol, ED, and scan length metrics for 2018-2021 for abdomen pelvis without contrast protocol as well as a statistical grouping summary of variable comparisons within sites. Means that do not share a letter are significantly different ($p < 0.05$). Institutional variation has proven to be much greater for RHCC protocol compared to non-head protocols. Most sites exhibited institutional differences in mean ED, H2 exhibited institutional differences in mean scan length, and H6 exhibited institutional differences in mean CTDIvol. Significant differences reported in H4 cf H5 appears to have contributions form scan length. Complete descriptive statistics for examined scan parameters are provided in the appendix (Table A.1-A.12).

Table 4.25 *Within site grouping information for routine head with/without contrast exam variables using the Tukey Method and 95% confidence (2018-2021)*

[A] CTDIvol (mGy)

H1			
Year	Mean	Grouping	
2018	55.01	A	B
2019	55.56	A	
2020	55.34	A	B
2021	54.84		B

H2			
Year	Mean	Grouping	
2018	58.51	A	B
2019	58.66	A	
2020	58.38		B
2021	58.65	A	B

H3			
Year	Mean	Grouping	
2018	63.30		B
2019	63.22		B
2020	66.86	A	
2021	63.11		B

H4			
Year	Mean	Grouping	
2018	61.14	A	
2019	61.11	A	
2020	61.20	A	
2021	61.08	A	

H5			
Year	Mean	Grouping	
2018	60.54	A	
2019	60.56	A	
2020	60.60	A	
2021	60.60	A	

H6			
Year	Mean	Grouping	
2018	59.31		C
2019	61.28	A	
2020	61.24	A	B
2021	60.96		B

[B] Scan Length (mm)

H1			
Year	Mean	Grouping	
2018	308.35	A	
2019	297.35	A	
2020	237.51		B
2021	260.35		B

H2			
Year	Mean	Grouping	
2018	364.37	A	
2019	366.51	A	
2020	297.07		C
2021	345.40	B	

H3			
Year	Mean	Grouping	
2018	286.60	A	
2019	285.19	A	
2020	196.10		B
2021	180.56		B

H4			
Year	Mean	Grouping	
2018	302.14	A	
2019	302.32	A	
2020	262.33		B
2021	264.86		B

H5			
Year	Mean	Grouping	
2018	338.96	A	
2019	277.06		B
2020	283.10		B
2021	279.04		B

H6			
Year	Mean	Grouping	
2018	342.85	A	
2019	307.97		B
2020	277.70		B
2021	284.00		B

[C] Effective Dose (mSv)

H1			
Year	Mean	Grouping	
2018	4.38	A	
2019	4.27	A	
2020	3.34		C
2021	3.69	B	

H2			
Year	Mean	Grouping	
2018	5.28	A	
2019	5.34	A	
2020	4.15		C
2021	5.03	B	

H3			
Year	Mean	Grouping	
2018	4.73	A	
2019	4.81	A	
2020	3.19		B
2021	3.15		B

H4			
Year	Mean	Grouping	
2018	4.72	A	
2019	4.76	A	
2020	3.73		C
2021	4.18	B	

H5			
Year	Mean	Grouping	
2018	5.32	A	
2019	4.38	B	
2020	3.51		C
2021	4.46	B	

H6			
Year	Mean	Grouping	
2018	5.08	A	
2019	4.89	A	
2020	3.90		C
2021	4.33	B	

4.3 Simple Linear Regression and Correlation Analysis between Patient Fluoroscopy Dose Variables

The following results address occupational dose received during interventional fluoroscopy procedures rather than patient dose during CT procedures which was investigated in a previous section. The relationship between two machine-generated dose variables was examined for a potential correlation to satisfy the study's objective. Machine-generated dose variables include RPD and DAP, which reflect the dose to the patient. Due to missing data, we were constrained to limit our analysis to the year 2020, as it was the only year to contain both variables of interest in full. Over the one-year study period, 860 patients received a cardiac or vascular fluoroscopy procedure in the Eastern Health region. The number of independent procedure protocols ranged from 45 in quarter one to 57 in quarter 4. All protocols were included in the model; each model represents a fiscal quarter in the year 2020, for a total of four models.

The regression models (Figure 5.1) depict the relationship between two dose variables, the log of RPD and the log of DAP. For this study, we are interested in the strength of the correlation between the two variables, and the uniformity of this relationship between quarters. The correlation coefficient- *r*, is listed in Table 4.39 for each quarter. Correlation coefficients are interpreted in two ways, direction of correlation and strength of correlation. A coefficient valued at +0.8 would suggest a strong positive correlation, and a correlation coefficient of +1.0 indicates a perfect positive correlation [57]. As the coefficient decreases, the strength of the relationship becomes weaker; a coefficient of zero indicates no association. The reported correlation coefficients confirm that log DAP and log RPD are strongly correlated in the positive direction for all four fiscal quarters (r= 0.97 [Q1], 0.98 [Q2], 0.97 [Q3], 0.98 [Q4]). Quarters 2 and 4

reported the strongest correlation (r=0.98). Although strongly correlated, DAP and RPD are not perfectly correlated (r=1.0).

Separate simple linear regression was conducted for the four quarters, results are shown in Table 4.39. Quarters 1 and 4 reported a R^2 of 0.95, suggesting that 95% of the data variability in DAP can be explained by RPD. The calculated R^2 for quarter 2 was 0.96, suggesting that 96% of the variability in DAP can be explained by RPD, and quarter 3 reported a R^2 of 0.94.

The regression equation calculated for each model may be used to give predicted Y (DAP) values. Data from quarter 1 offers the following regression equation; y= 0.88x – 1.15, where the predictor variable (x) represents the log of RPD, and the outcome variable (y) represents the log of DAP. The regression parameters are a= -1.15 (intercept) and b= 0.88 (slope) (Figure 5.1-A). The equations can be used to forecast DAP values when given RPD values. When RPD (x)=0, the DAP (y) value is -1.15. For every one-unit increase in RPD, the value of DAP will increase by an average of 0.88. Statistical analysis confirmed that intercept and slope are significant ($p<0.001$). Regression parameters vary for each of the models which will cause a slight variation to the outcome variable. Still, all models report statistical significance in the effects of both intercept and slope. For the purpose of the study, we were interested primarily in the strength of correlation between DAP and RPD and the ability to use DAP in place of RPD as another means of tracking occupational dose.

Table 4.26 *Missing dosimeter data for health care professionals involved in interventional cardio and vascular fluoroscopy procedures. Data includes all years combined (2016-2021). Overall sum includes all healthcare professions combined (radiologist, registered nurse, and radiology technologist). [A] Missing data from dosimeters tracking dose to whole body (chest). [B] Missing data from dosimeters tracking dose to extremities (wrist, arm, and collar).*

[A]

Fract missing.	Professional type	Readings	Missing
0.148	Overall sum	526	78
0.148	Rad sum.	162	24
0.224	RN sum.	107	24
0.117	RT sum.	257	30

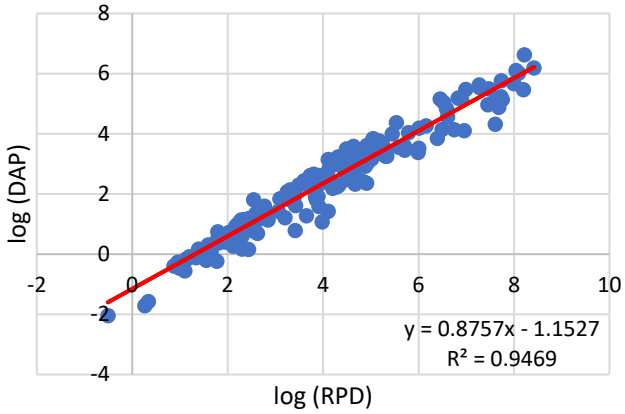
[B]

Fract missing.	Professional type	Readings	Missing
0.243	Overall sum	189	46
0.174	Rad sum.	92	16
0.263	RN sum.	38	10
0.339	RT sum.	59	20

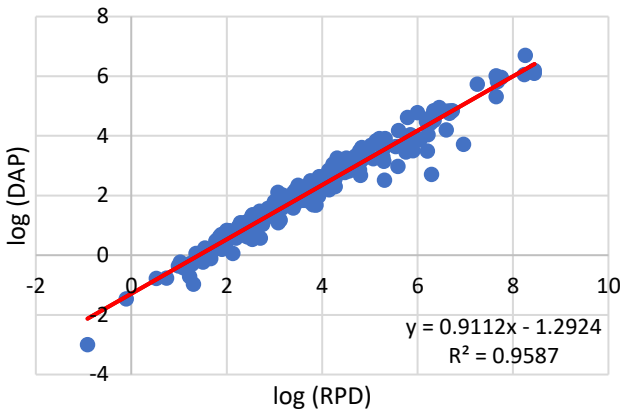
Table 4.27 *A regression analysis model summary by quarter for year 2020. (Q1: quarter 1, Q2: quarter 2, Q3: quarter 3, Q4: quarter 4).*

Regression statistic	Q1	Q2	Q3	Q4
Correlation coefficient (*r*)	0.97	0.98	0.97	0.98
R-squared (R^2)	0.95	0.96	0.94	0.95
Regression parameter	Q1	Q2	Q3	Q4
Intercept	-1.15	-1.29	-1.10	-1.17
Slope	0.88	0.91	0.88	0.88

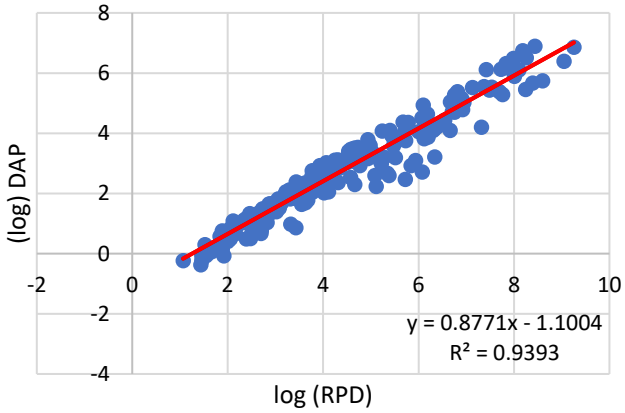
[A]



[B]



[C]



[D]

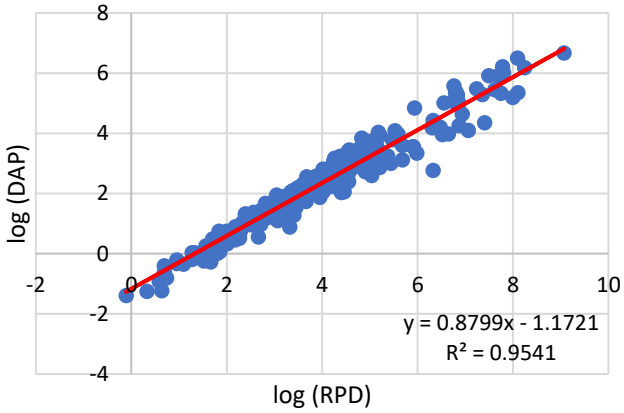


Figure 4.13 [A-D]: A. Quarter 1-2020 B. Quarter 2-2020 C. Quarter 3-2020; D. Quarter 4-2020. Scatter plots depicting the relationship between log-transformed dose area product (DAP) and log-transformed reference point dose (RPD) for cardiac and vascular fluoroscopy procedures performed in 2020.

Chapter 5 Discussion

5.1 Discussion (Patient Dose: CT Project)

The primary goal of the study was to examine patient dose and technical parameters from commonly performed CT exams to determine if there is difference between (1) average dose and scan parameters for different sites within the same region (province) and (2) differences in average dose and scan parameters within sites. Over the four-year study period, there was no upgrade of instrumentation used within the sites. Although patient characteristics play a role in measurable dose (i.e sex, size), the large patient population across sites was expected to follow an approximately normal distribution. However, it is noted that patient characteristics may be a confounding factor for this study. Further investigation will be needed to determine if these factors contributed to the observed differences.

Following the analysis of data, it was determined that radiation dose for all 12 protocols investigated differed considerably within and across sites. The effective dose was the variable used to investigate dose variation. To determine the source of variation, whether it be linked to how the equipment was used by staff (i.e. the technical parameters set by staff) or mechanics of the machine/model, both CTDIvol and scan length were investigated as contributing factors.

The CT scanners in this study electronically display CTDIvol after a completed scan. It is a useful measure of dose for a specific scan protocol. CTDIvol is predetermined and therefore fixed by the manufacturer and is expected to be unique for each scanner and model. Unlike other dose measures, CTDIvol is independent of patient size and length. The differences observed in CTDIvol can be credited to either the individual scanner or model and/or scan parameters

adjusted by staff. Significant differences in mean CTDIvol was observed for all protocols both within and across sites; however, the comparison within sites accounted for less observed differences between the means of site reported CTDIvol. These results were consistent with previous studies reporting observed CTDIvol differences across hospitals [50] [51] [52] [54] and between identical scanners housed by hospitals [56] for standard CT-protocols. These studies generally examined a few selected protocols. We chose to investigate a greater number of standard protocols that occur in medical imaging departments, including lumbar spine, renal colic, and pulmonary angiogram.

Large outliers in the dataset may have resulted in some of the observed differences. The report published in 2016 to determine national DRLs suggested some potential reasons for extremely high outliers if it can be determined they were a mistake [34]. For example, CTDIvol values may have been added over multiple sequences before being reported as a single value. The study also determined that certain models give the option to report the maximum CTDIvol rather than the average CTDIvol. Both reasons would result in a higher reported average after compiling all exam CTDIvol values.

Exam scan length was also investigated as a contributing factor to the significant differences observed in dose. Scan length was not investigated in prior publications, but its contribution to significant dose differences was found to be important in our study. Unlike CTDIvol, a patient's length directly influence exam scan length. An initial low-dose scan first maps the patient’s anatomy landmarks and then the technicians adjusts the final scan length as they see appropriate. Although the scan length depends on patient size and length, staff may overscan the acquisition length by a few centimetres to ensure no part of the region of interest is missed. Adding a few centimetres will result in a higher dose to the patient and will contribute to any variation

observed in scan length. Results from our study concluded significant scan length differences existed in each CT protocol between and within institutions. In addition to these findings large outliers were also observed in reported scan lengths. Some sites reported routine head exam scan lengths in the range of 800mm - 1400mm. Even when considering variation between the size of adult's heads, these large outliers would suggest that the area scanned included additional atomical areas. It is possible some routine head scans included the neck and chest region. In such cases it is important for sites to place such scans under the appropriate scan protocol.

The large dose difference observed between sites suggest the provinces medical imaging departments may benefit form protocol optimization strategies. Further investigation is needed to determine what strategies can be implemented to maintain quality while minimizing patient dose. During this study, CT image quality was not compared between sites. It was assumed that given the long history of operations at these sites, image quality would have achieved an acceptable diagnostic quality as judged by the reporting radiologists. However, it is possible that some image clarity may have been compromised by sites that reported lower doses. The trade-off between image clarity and noise is appropriate when the image still holds diagnostic capability. Evaluating sites that report low CTDIvol values is just as important as evaluating the sites reporting larger doses. Increased noise due to lower doses can result in an image with reduced diagnostic accuracy.

The dose differences observed in this study should encourage the province to develop provincial DRLs for common protocols. Without considering patient population factors, Newfoundland's reported average CTDIvol values fall below the DRLs reported for Canada for head, chest, and chest-abdomen-pelvis protocols [34]. Hospital 4 reported a slightly higher average CTDIvol in 2020 and 2021 compared to national DRLs, while the remaining sites were consistent with

national DRLs. This comparison is not exact due to the missing information relating to both the patient population (age, size, sex) and exam logistics (protocol specifics) in our studies reported averages.

Another explanation for dose differences in medical imaging departments is dose creep. Dose creep occurs when technicians make scan parameter judgements (e.g. increasing kVp, decreasing rotation time, decreasing pitch) to satisfy a large range of patient sizes [58]. This phenomenon can also help explain the differences observed in the contributing factors (CTDIvol and scan length). Generally, these changes are made to increase image quality by improving the signal to noise ratio, or increase resolution by collecting denser data. In both cases the side effect is increased patient dose.

It is also unknown if the sites reporting a higher procedural dose correlate with increased stochastic effects to the patient population compared to sites reporting a lower procedural dose for a comparable scan region. The linear non-threshold model currently used to guide radiation protection and management strategies suggests that the sites reporting a higher procedural dose impart a higher risk of stochastic effects to patients. Following the patient population may be a means to forecast stochastic effects from medical radiation exposure.

There are several limitations in this study that need to be acknowledged. First, the data used in this study did not exhibit a perfect normal distribution. Although each dataset met the requirements for pairwise comparison testing under the central limit theorem, there remains the possibility for false positives. Additionally, the study did not have data on patient's body habitus which can influence the radiation dose a patient receives. The evaluation of some scanning parameters which are associated with dose optimization such as kVp, pitch, and reconstruction

kernels were not included. This study seems to be the first of its kind within the province, so our goal was to first investigate whether we could confirm observable differences in dose between and within provincial medical imaging departments. Further, we included CTDIvol in our study which can account for some of these scan parameters. As stated above, we did not have information on image quality therefore we cannot be sure that sites reporting lower doses maintained the same level of diagnostic accuracy. However, it was assumed that the image quality would have met acceptable diagnostic standards assessed by the reporting radiologist.

5.2 Discussion (Occupational Dose: Fluoroscopy Project)

Healthcare professionals involved in Interventional procedures are exposed to possible ionizing radiation that can harm their health (stochastic effects). Interventional fluoroscopy procedures are becoming more frequent and involved, resulting in health care workers spending more time in procedure rooms and experiencing greater amounts of radiation. Even with all the technical advancements in medical imaging departments relating to patient care, there has been little advancement in the methods used to track occupational doses. Dosimetry badges are the most used method for monitoring occupational dose. They offer reliable dose integration over the observation period. However, they give no insight as to the nature of an exposure, nor when within the window an exposure occurred. This led us to develop a study that could provide an additional perspective for occupational dose monitoring. We proposed to test for a correlation between patient and staff dose. We theorized that patient dose estimates directly reflect the radiation used and therefore provide a direct measure of the potential exposure of the staff in the room. This method was developed with the limitations of dosimetry in mind including human error (forgotten badges, mistakenly exposed to direct radiation, and worn inappropriately) and

structural limitation with the device's ability to supply only cumulative dose for the quarter and not episodically.

Analysis of staff dosimetry data strengthened our argument for additional methods to track occupational dose to radiation and the prioritization of occupational health and safety for health care workers exposed to ionizing radiation. Dosimeter data from October 2016 to September 2021 was incomplete; missing quarterly exposure records made it difficult to draw inferences regarding a potential correlation between occupational and patient dose. Approximately 15% of badge readings measuring whole body dose were missing for all staff involved in interventional fluoroscopy procedures (radiologist, registered nurse, and medical radiation technologist). Registered nurses recorded the highest number of missing quarterly dose readings (22%) for whole body measures. Because of the extent of missing data, no formal conclusions can be made regarding the relationship between staff and patient dose.

In exploring the effectiveness of personal dosimetry as a sole method for tracking occupational dose, it is important to acknowledge the limitations inherent in this study. One notable limitation is the substantial number of missing quarterly readings, and uncertainties around whether these values were indeed unreported or if their absence resulted from unidentified factors. Potential explanations include the transition from National Dosimetry Service to the Landauer Dosimetry Service, each employing different record systems, or internal shifts in data custodianship during data collection. While the transition in dosimetry services does not entirely account for missing quarterly readings in later years, the retrospective nature of data collection and potential inconsistencies in recording methods could compromise the reliability and accuracy of quarterly reports. Despite these limitations, efforts were made to mitigate biases and ensure the validity of the conclusions drawn from the data.

We proposed to use Reference Point Dose as the patient dose variable. The National Council on Radiation Protection and Measurements (NCRP), the society of Interventional Radiology (SIR), and the cardiovascular and Interventional Radiological Society of Europe (CIRSE) recommended using reference point dose as the best approximation of patient entrance dose for interventional radiology [59] and thus the more suitable metric for estimation of occupational dose. Reference point dose was not available for all quarters however, dose area product was and so we examined the strength of relationship between RPD and DAP. The analysis was conducted quarterly for 2020 to produce four strongly correlated models (r= 0.97, 0.98, 0.97, 0.98). Such a strong correlation argues that DAP can be used as an approximation of patient dose when it is the only available data. It is worth noting however, that DAP data is ambiguous in that identical values can be obtained from low dose large area and large dose small area. These conditions would not produce a similar room dose from scattered radiation.

The relationship between RPD and DAP could be better refined with more contextual data. If this were available, a multiple linear regression analysis could help define any variables with a higher order effect or an unrecognized confounding variable that needs to be controlled for. We hypothesize that window size has an unknown effect however, unfortunately the data was unavailable to test its influence. Resolution of unknown effects would help produce a stronger model. In addition, the models can also be refined to reflect one type of procedure. The current models include both cardiac and vascular radiographic procedures conducted at Eastern Health during the study period.

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Appendix A

Analysis Tables

Table A.1: Descriptive Statistics for Annual Patient CTDIvol from Standard CT Protocols Performed in 2018

Hospital 1

	N	Mean	STDEV	Min	Max
APC-	188	9.30	5.53	2.70	48.40
APC+	499	9.84	6.57	2.20	54.80
CAPC-	72	7.56	3.04	2.00	16.60
CAPC+	316	7.20	4.41	1.70	23.99
CC-	165	4.27	2.24	1.80	18.80
CC+	178	3.92	2.10	1.20	14.50
LS	325	30.26	15.52	8.32	108.63
PA	47	10.56	4.90	3.28	26.35
RCOL	156	7.19	4.67	1.30	25.20
RHC-	545	54.57	3.38	30.50	65.80
RHCC	49	55.01	1.83	49.91	55.79
RHC+	161	55.07	2.96	25.13	55.79

Hospital 2

	N	Mean	STDEV	Min	Max
APC-	417	10.62	6.38	2.70	38.58
APC+	1268	10.78	6.51	4.58	46.20
CAPC-	116	9.19	4.41	3.10	24.10
CAPC+	973	9.20	4.49	4.16	30.07
CC-	362	8.61	4.54	1.50	21.90
CC+	542	9.26	4.54	2.90	22.30
LS	776	30.97	16.22	6.23	98.40
PA	196	10.46	6.22	1.70	44.70
RCOL	409	8.71	5.77	2.60	40.50
RHC-	774	58.46	2.32	28.80	69.60
RHCC	690	58.51	1.55	37.00	59.92
RHC+	125	57.99	3.28	40.59	58.70

Hospital 3

	N	Mean	STDEV	Min	Max
APC-	108	14.44	6.10	3.58	25.07
APC+	476	14.49	5.72	3.93	24.42
CAPC-	32	11.60	5.84	3.83	21.18
CAPC+	528	12.92	5.34	3.49	32.12
CC-	331	12.33	4.64	2.48	19.02
CC+	358	11.99	4.63	3.46	21.22
LS	313	24.26	11.02	5.85	42.26
PA	64	16.77	5.32	4.34	31.21
RCOL	138	14.11	5.76	3.46	24.16
RHC-	532	63.17	0.78	53.75	68.59
RHCC	32	63.30	0.47	61.51	63.91
RHC+	333	63.22	2.27	26.95	80.25

Hospital 4

	N	Mean	STDEV	Min	Max
APC-	488	10.69	9.47	2.10	67.40
APC+	1784	12.07	9.19	2.80	74.18
CAPC-	80	10.07	6.57	4.60	34.01
CAPC+	620	8.86	6.37	2.06	44.22
CC-	405	4.80	3.44	0.30	30.72
CC+	368	4.28	2.67	1.20	32.32
LS	388	30.85	18.67	7.51	82.66
PA	544	9.74	5.79	2.04	28.83
RCOL	440	8.44	7.36	2.10	59.47
RHC-	2155	60.93	2.99	36.68	79.89
RHCC	263	61.14	0.81	55.42	61.52
RHC+	410	58.57	7.05	32.42	79.58

Hospital 5

	N	Mean	STDEV	Min	Max
APC-	268	15.22	7.38	4.66	43.67
APC+	983	14.09	7.02	3.25	44.92
CAPC-	167	10.18	4.01	4.61	28.97
CAPC+	1533	11.00	4.74	4.03	36.79
CC-	815	9.55	4.25	2.99	32.11
CC+	430	9.65	4.44	3.32	32.10
LS	1181	38.04	20.02	9.91	149.00
PA	110	16.60	8.75	6.17	55.96
RCOL	337	13.70	6.31	5.56	42.02
RHC-	625	60.09	2.94	24.56	64.30
RHCC	137	60.54	0.69	52.50	60.60
RHC+	346	60.33	2.15	27.60	60.60

Hospital 6

	N	Mean	STDEV	Min	Max
APC-	423	9.66	7.46	2.20	48.80
APC+	2045	11.76	9.37	4.10	73.60
CAPC-	81	9.29	7.17	2.60	35.00
CAPC+	957	9.02	6.23	1.90	59.92
CC-	758	7.45	5.42	0.30	48.10
CC+	704	7.43	5.22	1.70	41.90
LS	533	30.28	16.11	12.70	82.68
PA	311	9.62	6.84	1.74	44.60
RCOL	349	7.86	6.43	2.00	53.60
RHC-	1414	59.35	2.77	17.90	71.59
RHCC	307	59.31	1.99	48.04	61.52
RHC+	586	59.33	2.12	27.60	60.60

Table A.2: Descriptive Statistics for Annual Patient Scan Length from Standard CT Protocols Performed in 2018

Hospital 1

	N	Mean	STDEV	Min	Max
APC-	188	513.20	149.00	192.00	1940.90
APC+	499	501.90	55.72	319.33	1122.42
CAPC-	72	687.39	71.24	192.50	794.43
CAPC+	316	899.01	69.69	689.32	1380.56
CC-	165	433.28	100.54	317.08	857.14
CC+	178	411.40	26.95	340.32	517.89
LS	325	245.86	28.29	76.97	486.96
PA	47	388.69	40.91	334.74	525.98
RCOL	156	497.58	52.46	399.03	962.83
RHC-	545	163.43	45.36	114.00	477.26
RHCC	49	308.35	39.69	194.18	496.12
RHC+	161	158.26	32.33	150.99	345.17

Hospital 2

	N	Mean	STDEV	Min	Max
APC-	417	578.64	135.95	420.00	1633.76
APC+	1268	554.76	67.15	176.09	1042.60
CAPC-	116	741.50	121.90	475.40	1696.00
CAPC+	973	931.76	79.81	469.81	1486.98
CC-	362	415.58	91.80	307.18	1356.32
CC+	542	404.33	85.73	292.58	1629.73
LS	776	224.12	90.53	121.38	1785.28
PA	196	393.90	168.70	8.00	1450.30
RCOL	409	555.79	127.05	411.48	1533.95
RHC-	774	192.96	42.24	122.12	662.84
RHCC	690	364.37	58.74	140.70	810.89
RHC+	125	199.74	52.96	159.76	619.80

Hospital 3

	N	Mean	STDEV	Min	Max
APC-	108	485.89	57.22	273.97	643.17
APC+	476	521.63	62.70	5.00	1040.32
CAPC-	32	839.79	50.02	729.00	915.42
CAPC+	528	855.31	48.28	567.17	1239.85
CC-	331	360.44	45.05	284.74	659.31
CC+	358	359.42	43.76	198.05	872.91
LS	313	255.86	21.32	160.35	391.64
PA	64	405.57	38.20	346.14	538.73
RCOL	138	447.00	33.90	184.98	522.49
RHC-	532	143.73	12.23	100.00	283.10
RHCC	32	286.60	9.02	279.99	313.43
RHC+	333	142.77	8.88	130.17	237.67

Hospital 4

	N	Mean	STDEV	Min	Max
APC-	488	525.82	124.70	159.88	1646.70
APC+	1784	519.61	83.14	269.20	1621.49
CAPC-	80	706.15	86.60	520.56	1234.39
CAPC+	620	886.31	120.01	327.95	2066.87
CC-	405	410.01	142.64	119.55	1506.82
CC+	368	378.70	78.69	202.61	860.66
LS	388	216.69	49.99	114.03	534.04
PA	544	365.65	100.17	240.51	1102.03
RCOL	440	508.83	89.12	398.65	1647.44
RHC-	2155	175.65	98.67	40.02	1477.78
RHCC	263	302.14	41.24	151.00	639.80
RHC+	410	170.71	80.95	76.99	1339.58

Hospital 5

	N	Mean	STDEV	Min	Max
APC-	268	537.33	119.88	181.34	1833.77
APC+	983	534.05	65.03	266.34	1168.82
CAPC-	167	864.39	111.55	182.17	1654.62
CAPC+	1534	878.92	69.86	82.24	1587.84
CC-	816	384.23	101.07	247.42	1094.11
CC+	430	369.20	93.45	284.76	1846.76
LS	1181	251.05	23.11	114.69	515.24
PA	110	380.50	127.20	10.00	1044.30
RCOL	337	526.66	63.77	349.34	1384.51
RHC-	625	183.37	49.38	130.00	558.52
RHCC	137	338.96	34.53	140.00	401.67
RHC+	346	174.38	20.96	40.56	361.11

Hospital 6

	N	Mean	STDEV	Min	Max
APC-	423	533.08	160.14	275.23	1780.72
APC+	2045	505.24	67.41	57.21	1689.79
CAPC-	81	659.70	138.10	411.70	1540.20
CAPC+	957	871.78	84.83	337.34	2112.52
CC-	758	395.19	93.41	150.43	1484.85
CC+	704	385.06	38.26	278.70	818.33
LS	533	253.39	40.27	126.93	631.97
PA	311	366.56	95.38	15.96	1285.61
RCOL	349	499.61	58.74	398.09	1057.50
RHC-	1418	192.94	107.04	40.02	1310.63
RHCC	307	342.85	51.38	151.00	563.96
RHC+	586	188.93	86.46	40.56	1314.26

Table A.3: Descriptive Statistics for Annual Patient Effective Dose from Standard CT Protocols Performed in 2018

Hospital 1

	N	Mean	STDEV	Min	Max
APC-	188	6.95	4.47	1.60	42.52
APC+	499	10.60	7.70	2.29	67.88
CAPC-	72	7.87	2.50	1.17	16.14
CAPC+	317	9.58	4.94	2.31	28.05
CC-	165	3.19	1.79	1.57	11.08
CC+	178	2.35	0.94	0.97	6.45
LS	325	18.97	10.38	2.49	82.17
PA	47	6.17	2.22	2.39	12.35
RCOL	156	5.24	3.11	1.05	21.99
RHC-	545	2.28	0.54	1.26	6.32
RHCC	49	4.38	0.65	2.37	6.93
RHC+	161	2.28	0.39	1.83	4.93

Hospital 2

	N	Mean	STDEV	Min	Max
APC-	417	8.87	5.31	2.85	51.73
APC+	1268	8.78	4.26	2.24	36.53
CAPC-	116	9.82	3.82	4.07	23.81
CAPC+	973	12.82	4.91	4.70	51.38
CC-	362	6.01	2.74	1.55	22.28
CC+	542	6.26	2.56	1.75	21.55
LS	776	17.86	10.48	4.60	71.03
PA	196	7.43	4.51	0.09	24.05
RCOL	409	6.97	4.19	2.35	35.63
RHC-	774	2.78	0.54	0.86	7.50
RHCC	690	5.28	0.83	1.99	8.57
RHC+	126	2.87	0.65	2.23	7.43

Hospital 3

	N	Mean	STDEV	Min	Max
APC-	108	10.18	3.25	3.73	17.36
APC+	477	11.47	3.72	0.10	25.64
CAPC-	32	16.25	5.95	7.82	29.30
CAPC+	528	17.48	6.02	5.34	44.40
CC-	331	8.20	2.56	1.76	14.90
CC+	358	7.89	2.56	2.71	19.47
LS	313	15.48	7.41	2.02	30.92
PA	64	12.76	3.49	4.14	18.47
RCOL	138	9.36	3.17	2.55	16.10
RHC-	532	2.39	0.27	1.60	5.02
RHCC	32	4.73	0.35	4.29	5.40
RHC+	333	2.43	0.59	2.14	12.52

Hospital 4

	N	Mean	STDEV	Min	Max
APC-	488	8.19	6.80	1.89	52.48
APC+	1784	9.46	6.69	2.46	98.46
CAPC-	80	9.67	5.34	5.27	38.78
CAPC+	620	12.15	7.98	1.69	61.45
CC-	405	3.50	2.96	0.16	29.90
CC+	368	2.57	2.30	0.83	35.73
LS	388	16.53	10.16	3.66	48.89
PA	544	6.47	4.18	1.87	34.67
RCOL	440	6.36	5.29	2.08	67.39
RHC-	2155	2.63	1.06	0.60	17.16
RHCC	263	4.72	0.73	2.21	9.07
RHC+	410	2.57	1.26	0.63	25.26

Hospital 5

	N	Mean	STDEV	Min	Max
APC-	268	11.91	6.18	3.97	75.16
APC+	983	11.40	4.46	2.83	33.53
CAPC-	167	14.00	4.49	4.64	37.68
CAPC+	1534	15.17	4.96	2.50	47.35
CC-	816	6.21	2.01	0.92	22.78
CC+	430	6.25	2.37	2.56	31.49
LS	1181	23.56	13.07	5.14	91.62
PA	110	11.84	5.48	0.39	44.73
RCOL	337	10.74	3.78	5.14	29.71
RHC-	625	2.76	0.89	1.89	14.88
RHCC	138	5.32	1.80	2.04	25.25
RHC+	347	2.70	1.56	0.80	30.96

Hospital 6

	N	Mean	STDEV	Min	Max
APC-	423	7.59	6.16	1.83	66.74
APC+	2046	8.84	5.98	0.51	55.64
CAPC-	81	8.86	6.38	3.05	34.16
CAPC+	957	12.05	6.72	1.72	74.64
CC-	758	5.10	3.19	0.16	27.97
CC+	704	4.56	2.57	1.43	28.24
LS	533	19.07	10.01	3.85	60.88
PA	312	6.15	4.21	0.13	31.85
RCOL	349	5.88	4.06	1.98	39.05
RHC-	1419	2.77	1.24	0.44	31.28
RHCC	307	5.08	0.66	2.53	7.94
RHC+	587	2.81	1.64	0.80	30.96

Table A.4: Descriptive Statistics for Annual Patient CTDIvol from Standard CT Protocols Performed in 2019

Hospital 1

	N	Mean	STDEV	Min	Max
APC-	149	9.77	5.27	2.80	31.10
APC+	488	9.69	5.77	2.70	38.10
CAPC-	94	8.14	3.13	3.20	18.20
CAPC+	366	6.89	4.48	1.20	30.12
CC-	168	3.96	1.79	1.40	13.40
CC+	233	4.00	2.33	1.10	15.00
LS	356	26.47	12.45	8.38	78.63
PA	40	8.63	6.19	2.77	37.96
RCOL	188	7.81	5.77	2.20	39.40
RHC-	588	54.96	2.56	32.03	56.16
RHCC	65	55.56	1.07	50.75	56.01
RHC+	152	55.03	2.53	40.89	56.16

Hospital 2

	N	Mean	STDEV	Min	Max
APC-	276	11.68	7.53	4.41	46.20
APC+	1350	10.89	6.75	5.20	44.97
CAPC-	141	9.71	5.03	3.20	23.70
CAPC+	1055	8.98	4.45	4.18	27.89
CC-	295	9.18	4.49	3.10	24.31
CC+	537	9.32	4.63	2.90	24.10
LS	761	32.38	16.68	6.28	98.40
PA	244	11.52	7.13	1.60	43.91
RCOL	540	8.77	6.19	2.60	45.87
RHC-	876	58.52	1.76	38.67	69.60
RHCC	697	58.66	0.84	38.73	58.70
RHC+	124	58.43	2.10	42.03	58.70

Hospital 3

	N	Mean	STDEV	Min	Max
APC-	60	14.66	5.67	5.26	22.47
APC+	585	14.18	5.82	3.65	24.64
CAPC-	58	14.33	5.18	4.12	21.06
CAPC+	515	12.91	5.33	3.46	21.24
CC-	356	12.63	4.60	3.46	20.74
CC+	336	12.73	4.66	3.46	19.02
LS	373	24.27	10.57	5.63	41.41
PA	65	15.88	5.05	4.55	29.89
RCOL	215	14.09	5.81	4.37	25.93
RHC-	583	63.20	1.87	39.75	88.01
RHCC	44	63.22	0.58	61.51	64.96
RHC+	362	63.32	0.62	61.27	68.73

Hospital 4

	N	Mean	STDEV	Min	Max
APC-	414	11.56	9.05	2.91	67.40
APC+	2508	12.05	9.35	2.80	84.80
CAPC-	120	9.87	7.44	3.00	46.50
CAPC+	740	8.06	5.89	2.34	58.49
CC-	406	4.57	3.07	1.30	23.90
CC+	496	4.13	2.42	1.00	20.00
LS	648	30.51	20.10	5.08	146.50
PA	705	10.21	7.68	1.76	101.97
RCOL	707	8.95	7.77	2.10	72.00
RHC-	2530	60.74	3.60	29.32	79.89
RHCC	382	61.11	0.93	55.42	61.52
RHC+	492	58.29	7.27	29.32	61.52

Hospital 5

	N	Mean	STDEV	Min	Max
APC-	105	14.30	7.17	5.82	47.14
APC+	743	14.72	6.86	5.10	48.66
CAPC-	124	9.58	3.40	4.17	21.14
CAPC+	1298	11.31	5.08	3.24	37.77
CC-	801	10.01	5.14	2.36	40.38
CC+	396	9.78	4.73	3.47	40.54
LS	1220	37.63	19.36	10.36	152.13
PA	25	16.39	9.73	5.78	51.17
RCOL	378	14.25	6.81	5.21	44.19
RHC-	534	60.55	1.10	35.29	61.78
RHCC	140	60.56	0.45	55.28	60.60
RHC+	296	60.60	0.00	60.60	60.60

Hospital 6

	N	Mean	STDEV	Min	Max
APC-	245	9.67	7.39	2.60	49.41
APC+	2103	12.21	9.96	4.10	67.00
CAPC-	85	7.89	3.59	2.30	18.80
CAPC+	1164	9.60	6.46	3.11	57.62
CC-	728	7.46	5.04	2.20	41.50
CC+	739	7.48	4.64	1.80	35.60
LS	672	34.89	15.91	10.89	73.78
PA	333	11.00	14.36	2.17	244.56
RCOL	577	8.70	7.26	2.10	63.90
RHC-	1243	61.12	1.59	39.29	74.32
RHCC	269	61.28	0.85	55.42	69.12
RHC+	512	61.07	2.50	37.85	79.26

Table A.5: Descriptive Statistics for Annual Patient Scan Length from Standard CT Protocols Performed in 2019

Hospital 1

	N	Mean	STDEV	Min	Max
APC-	149	509.00	147.40	319.60	2095.90
APC+	488	498.77	53.86	346.38	1234.72
CAPC-	94	692.94	39.59	582.34	833.81
CAPC+	366	900.16	69.26	160.83	1286.42
CC-	168	426.19	57.13	351.58	836.88
CC+	233	420.47	37.39	192.67	818.87
LS	356	239.76	26.65	77.00	373.04
PA	40	357.10	113.50	16.00	548.60
RCOL	188	490.20	53.50	384.06	932.49
RHC-	588	163.10	51.52	150.99	884.72
RHCC	65	297.35	31.69	150.99	376.00
RHC+	152	156.36	23.81	150.99	276.06

Hospital 2

	N	Mean	STDEV	Min	Max
APC-	276	589.90	168.30	242.70	1557.20
APC+	1350	556.05	69.85	263.46	1176.86
CAPC-	141	768.50	203.70	533.90	2172.90
CAPC+	1055	926.32	80.97	26.00	1388.89
CC-	295	414.01	161.72	264.80	2409.54
CC+	537	396.34	51.42	276.60	860.16
LS	761	230.63	87.91	150.00	1621.35
PA	244	354.15	107.40	8.03	973.08
RCOL	540	551.81	129.36	408.93	1478.62
RHC-	876	193.96	46.49	111.75	741.84
RHCC	697	366.51	41.32	159.76	558.33
RHC+	124	187.17	26.20	124.80	339.23

Hospital 3

	N	Mean	STDEV	Min	Max
APC-	60	504.28	42.33	424.42	658.35
APC+	585	511.10	52.16	5.00	1008.85
CAPC-	58	834.65	45.29	717.30	909.83
CAPC+	515	848.83	46.54	712.05	1150.14
CC-	356	358.98	30.86	280.42	631.13
CC+	336	359.71	27.78	291.11	467.62
LS	373	248.70	15.38	207.86	322.97
PA	65	404.85	59.86	73.42	602.73
RCOL	215	444.93	52.83	378.59	1069.07
RHC-	584	146.61	29.58	20.00	699.70
RHCC	44	285.19	25.84	140.08	329.11
RHC+	362	142.77	8.43	130.00	261.95

Hospital 4

	N	Mean	STDEV	Min	Max
APC-	414	567.70	253.50	220.00	2766.60
APC+	2508	514.81	64.49	211.35	1122.05
CAPC-	120	748.70	305.70	428.80	2679.30
CAPC+	740	869.58	81.16	455.29	1942.07
CC-	406	375.75	89.09	130.71	1103.98
CC+	496	370.63	75.36	271.67	1488.21
LS	648	211.03	65.75	114.00	1272.85
PA	705	352.47	67.92	7.73	1088.47
RCOL	707	507.89	75.79	335.67	1381.05
RHC-	2530	177.20	110.24	76.99	2076.63
RHCC	382	302.32	27.56	151.00	453.01
RHC+	492	172.63	85.30	76.99	1514.28

Hospital 5

	N	Mean	STDEV	Min	Max
APC-	105	514.12	62.97	206.89	655.80
APC+	743	525.47	64.79	287.65	1564.27
CAPC-	124	695.64	109.35	451.72	1317.34
CAPC+	1298	868.07	65.05	368.92	1515.94
CC-	801	392.04	113.83	246.07	1073.53
CC+	396	358.20	47.73	276.67	916.45
LS	1220	248.20	26.46	130.95	661.79
PA	25	445.80	152.20	329.60	1095.10
RCOL	378	523.64	76.78	416.15	1814.86
RHC-	534	142.16	14.71	130.00	290.00
RHCC	140	277.06	33.76	130.00	361.11
RHC+	296	141.77	11.17	120.00	280.00

Hospital 6

	N	Mean	STDEV	Min	Max
APC-	245	547.90	165.70	259.80	2204.50
APC+	2103	524.52	67.15	192.03	1161.56
CAPC-	85	678.70	99.80	426.10	1054.40
CAPC+	1164	901.62	72.63	383.47	1544.50
CC-	728	405.23	95.67	283.85	1461.99
CC+	739	391.52	38.10	297.24	773.19
LS	672	245.24	57.54	114.00	1141.50
PA	333	381.47	55.96	11.93	823.90
RCOL	577	523.57	82.98	400.00	1780.09
RHC-	1243	192.38	142.11	77.00	1105.40
RHCC	269	307.97	37.75	151.00	603.99
RHC+	512	218.90	233.70	151.00	1683.80

Table A.6: Descriptive Statistics for Annual Patient Effective Dose from Standard CT Protocols Performed in 2019

Hospital 1

	N	Mean	STDEV	Min	Max
APC-	149	7.27	3.35	2.77	21.88
APC+	488	10.45	6.79	2.90	48.20
CAPC-	94	8.28	2.53	4.50	20.85
CAPC+	366	9.52	4.87	0.52	34.46
CC-	168	2.91	1.00	1.60	7.60
CC+	233	2.44	1.11	0.80	8.40
LS	356	16.03	7.99	4.92	56.91
PA	40	5.04	3.31	0.26	19.68
RCOL	188	5.44	3.31	1.81	24.80
RHC-	588	2.30	0.60	1.83	9.37
RHCC	65	4.27	0.54	2.01	5.21
RHC+	152	2.25	0.27	1.83	3.39

Hospital 2

	N	Mean	STDEV	Min	Max
APC-	276	9.70	5.54	1.73	40.37
APC+	1350	8.88	4.71	2.94	50.95
CAPC-	141	10.45	5.07	4.71	39.73
CAPC+	1055	12.63	4.69	1.75	33.68
CC-	295	6.36	3.88	2.54	52.62
CC+	537	6.21	2.50	2.61	16.82
LS	761	19.11	11.05	5.62	75.95
PA	244	6.96	3.71	0.08	17.80
RCOL	540	7.08	5.51	2.38	69.03
RHC-	876	2.79	0.57	1.89	7.93
RHCC	697	5.34	0.63	2.34	7.84
RHC+	124	2.71	0.37	1.78	4.28

Hospital 3

	N	Mean	STDEV	Min	Max
APC-	60	11.03	3.41	4.75	19.29
APC+	585	11.10	3.58	0.07	19.68
CAPC-	58	18.17	5.61	5.86	27.35
CAPC+	515	17.33	5.91	4.83	29.30
CC-	356	8.10	2.33	3.42	16.89
CC+	336	8.25	2.44	3.38	14.34
LS	373	15.21	6.83	3.39	29.16
PA	65	12.36	3.61	0.71	22.34
RCOL	215	9.38	3.45	4.33	32.51
RHC-	584	2.44	0.26	0.58	4.30
RHCC	44	4.81	0.52	2.50	6.29
RHC+	362	2.43	0.22	2.14	4.73

Hospital 4

	N	Mean	STDEV	Min	Max
APC-	414	9.84	10.42	2.32	132.49
APC+	2508	9.35	6.56	1.61	86.19
CAPC-	120	10.75	8.90	2.91	53.79
CAPC+	740	10.88	6.57	3.35	69.41
CC-	406	2.95	1.85	0.73	20.44
CC+	496	2.39	1.31	0.78	13.22
LS	648	16.60	11.55	3.61	96.82
PA	705	6.48	4.01	0.03	27.09
RCOL	707	6.74	5.27	1.77	45.77
RHC-	2530	2.61	1.03	0.63	16.98
RHCC	382	4.76	0.54	2.21	7.71
RHC+	492	2.54	0.72	0.63	11.82

Hospital 5

	N	Mean	STDEV	Min	Max
APC-	105	10.91	3.93	5.10	25.18
APC+	743	11.53	4.26	3.80	38.95
CAPC-	124	9.76	3.44	5.19	31.80
CAPC+	1298	15.41	5.39	3.65	53.31
CC-	801	6.51	2.34	3.03	29.11
CC+	396	6.15	2.31	3.08	22.75
LS	1220	22.96	12.26	5.94	105.16
PA	25	12.48	3.93	7.13	23.11
RCOL	378	11.01	4.34	5.03	44.02
RHC-	534	2.26	0.24	1.91	4.74
RHCC	140	4.38	0.57	1.91	5.44
RHC+	296	2.27	0.21	1.91	4.74

Hospital 6

	N	Mean	STDEV	Min	Max
APC-	245	8.15	7.83	2.36	83.43
APC+	2103	9.54	6.70	1.97	63.78
CAPC-	85	7.67	2.61	2.89	14.79
CAPC+	1164	12.78	7.10	4.26	65.01
CC-	728	5.16	2.89	2.08	22.36
CC+	739	4.62	2.51	1.19	22.47
LS	672	21.14	9.88	7.13	59.44
PA	333	7.12	4.19	1.71	27.80
RCOL	577	6.63	4.65	1.72	40.84
RHC-	1243	2.71	1.15	1.43	19.00
RHCC	269	4.89	0.64	2.21	8.45
RHC+	512	3.10	2.49	2.21	25.56

Table A.7: Descriptive Statistics for Annual Patient CTDIvol from Standard CT Protocols Performed in 2020

Hospital 1

	N	Mean	STDEV	Min	Max
APC-	122	10.34	6.16	2.30	30.90
APC+	490	9.83	6.26	2.60	41.89
CAPC-	72	8.10	3.39	3.10	18.90
CAPC+	460	6.64	4.50	1.30	29.10
CC-	144	4.60	3.16	1.80	27.80
CC+	226	3.80	2.17	1.20	14.00
LS	296	30.11	14.62	9.15	126.90
PA	77	23.83	37.54	3.24	204.70
RCOL	146	7.82	5.26	2.30	29.70
RHC-	545	54.13	3.82	15.30	56.01
RHCC	104	55.34	1.43	50.75	55.79
RHC+	128	54.06	3.63	30.50	56.01

Hospital 2

	N	Mean	STDEV	Min	Max
APC-	206	12.68	9.34	5.20	86.80
APC+	1055	10.92	6.83	5.20	46.00
CAPC-	137	9.42	5.70	3.10	27.20
CAPC+	1090	9.43	4.50	3.10	32.40
CC-	247	9.41	6.88	2.90	86.80
CC+	461	8.90	4.34	2.90	23.40
LS	675	33.17	17.49	4.70	97.00
PA	286	31.37	65.59	1.70	522.80
RCOL	424	9.03	5.93	2.70	49.10
RHC-	738	58.06	5.02	12.40	69.60
RHCC	664	58.38	3.40	12.40	58.70
RHC+	157	58.36	2.46	40.34	58.70

Hospital 3

	N	Mean	STDEV	Min	Max
APC-	79	15.56	5.66	3.75	24.14
APC+	582	16.33	7.05	2.82	56.34
CAPC-	51	12.39	4.57	4.42	21.82
CAPC+	693	12.94	5.19	3.46	22.47
CC-	321	12.59	4.54	3.61	20.74
CC+	302	12.32	4.55	3.46	19.02
LS	278	23.84	10.98	5.67	39.44
PA	73	13.64	7.22	2.82	39.44
RCOL	168	14.05	5.89	3.81	24.89
RHC-	638	66.39	11.25	27.74	88.01
RHCC	31	66.86	12.28	53.50	87.97
RHC+	319	65.97	10.44	47.99	88.01

Hospital 4

	N	Mean	STDEV	Min	Max
APC-	367	18.15	13.13	1.30	87.90
APC+	2253	16.33	10.87	3.00	80.40
CAPC-	104	13.96	7.91	3.80	36.10
CAPC+	1045	10.72	7.64	1.50	57.80
CC-	403	6.81	8.23	1.50	143.30
CC+	404	5.77	3.72	0.80	48.00
LS	651	42.98	20.17	9.09	115.01
PA	992	33.65	61.96	2.20	664.40
RCOL	510	11.98	9.23	2.20	60.70
RHC-	2383	60.83	3.98	11.50	79.89
RHCC	419	61.20	1.14	55.42	79.58
RHC+	355	57.57	9.06	11.50	79.58

Hospital 5

	N	Mean	STDEV	Min	Max
APC-	98	13.96	7.02	4.91	36.36
APC+	817	14.64	7.16	4.50	56.80
CAPC-	118	10.10	3.61	4.38	23.32
CAPC+	1649	11.27	5.64	2.63	40.51
CC-	556	9.74	5.31	1.00	43.80
CC+	454	9.84	4.77	1.30	43.17
LS	710	30.83	18.92	7.63	136.21
PA	62	13.55	7.13	6.73	36.62
RCOL	235	13.97	6.61	5.45	40.73
RHC-	379	60.52	1.60	29.50	60.60
RHCC	144	60.60	0.00	60.60	60.60
RHC+	301	60.52	1.35	37.11	60.60

Hospital 6

	N	Mean	STDEV	Min	Max
APC-	294	11.00	7.93	2.70	41.90
APC+	2014	11.86	9.59	4.10	68.80
CAPC-	95	9.22	7.06	2.40	41.60
CAPC+	1543	8.81	5.95	2.00	61.80
CC-	704	7.46	5.13	1.60	38.90
CC+	693	7.27	4.65	1.70	40.00
LS	664	35.26	16.17	7.74	75.74
PA	484	20.68	38.05	2.13	336.80
RCOL	428	8.80	8.40	2.30	73.40
RHC-	1149	60.95	2.85	19.00	76.59
RHCC	323	61.24	0.47	55.42	61.52
RHC+	451	60.86	2.67	38.20	61.52

Table A.8: Descriptive Statistics for Annual Patient Scan Length from Standard CT Protocols Performed in 2020

Hospital 1

	N	Mean	STDEV	Min	Max
APC-	122	527.90	143.60	72.30	1258.30
APC+	491	513.27	152.07	15.96	2065.13
CAPC-	74	683.40	136.70	150.40	1004.60
CAPC+	461	666.00	264.00	16.00	2783.10
CC-	144	430.42	89.64	140.54	1000.00
CC+	227	458.80	198.00	16.00	2065.20
LS	295	273.26	160.08	15.96	2203.66
PA	77	230.70	195.20	2.00	589.30
RCOL	146	508.91	117.31	16.00	1099.27
RHC-	547	203.24	191.21	15.96	2806.23
RHCC	104	237.51	92.35	140.91	539.35
RHC+	129	196.80	156.00	40.00	932.10

Hospital 2

	N	Mean	STDEV	Min	Max
APC-	206	611.00	263.90	2.00	1883.50
APC+	1055	553.49	114.04	33.22	2106.83
CAPC-	137	717.80	210.30	151.00	2327.90
CAPC+	1090	695.21	263.81	109.81	1714.74
CC-	247	413.57	137.65	2.00	1655.87
CC+	461	415.80	138.35	127.81	2089.54
LS	675	241.57	126.27	135.00	1900.82
PA	286	273.20	217.70	2.00	1556.00
RCOL	424	558.42	169.68	151.00	1833.22
RHC-	737	218.74	163.05	2.02	2090.01
RHCC	664	297.07	135.07	2.02	1091.89
RHC+	158	226.00	154.20	129.90	1194.50

Hospital 3

	N	Mean	STDEV	Min	Max
APC-	79	497.50	120.00	151.00	1219.60
APC+	582	411.34	227.76	5.00	1553.34
CAPC-	50	674.10	222.10	170.00	952.30
CAPC+	693	655.47	250.81	15.96	1848.09
CC-	321	390.00	194.00	16.00	2520.10
CC+	302	371.62	90.86	99.96	964.09
LS	278	259.03	77.82	15.99	941.64
PA	73	253.60	191.90	5.00	815.90
RCOL	168	443.01	116.53	148.29	1175.25
RHC-	638	139.57	181.85	5.00	2456.52
RHCC	31	196.10	145.70	15.00	659.80
RHC+	319	130.89	123.38	5.00	1502.86

Hospital 4

	N	Mean	STDEV	Min	Max
APC-	366	538.70	257.00	11.80	2223.20
APC+	2253	526.92	138.92	15.96	2397.14
CAPC-	104	706.60	283.50	16.00	2765.60
CAPC+	1044	677.87	249.62	15.99	1657.41
CC-	403	408.60	201.20	4.00	2263.60
CC+	404	392.14	153.54	15.99	2080.07
LS	651	223.52	133.80	15.99	2173.03
PA	992	255.06	219.61	3.99	2408.88
RCOL	510	496.67	153.31	15.99	1722.31
RHC-	2399	209.83	197.22	1.98	2429.16
RHCC	419	262.33	172.71	40.02	1349.22
RHC+	358	187.29	143.34	1.98	1318.09

Hospital 5

	N	Mean	STDEV	Min	Max
APC-	99	520.50	189.50	189.70	1905.90
APC+	817	519.68	152.61	91.65	2437.16
CAPC-	118	668.20	219.20	77.00	2083.00
CAPC+	1648	643.48	249.87	15.96	1813.26
CC-	556	392.81	154.07	10.00	1832.69
CC+	453	375.96	155.46	139.99	1735.77
LS	710	251.94	78.12	101.24	1595.75
PA	62	262.00	270.80	10.00	1218.20
RCOL	235	522.40	197.60	16.00	2453.10
RHC-	379	163.19	106.79	9.99	947.17
RHCC	144	283.10	321.70	60.00	3328.70
RHC+	301	173.01	144.61	9.99	1070.79

Hospital 6

	N	Mean	STDEV	Min	Max
APC-	294	524.60	238.90	4.00	2916.10
APC+	2015	526.67	159.10	15.99	2777.38
CAPC-	95	653.00	234.50	136.20	2297.60
CAPC+	1541	682.07	259.07	15.96	1799.58
CC-	703	383.89	164.14	12.07	1491.94
CC+	693	411.22	156.27	15.99	2067.37
LS	664	265.72	159.96	16.00	2794.54
PA	484	244.73	205.87	3.98	1309.67
RCOL	428	511.13	152.03	15.96	1366.17
RHC-	1175	214.50	191.68	3.99	1415.59
RHCC	323	277.70	235.10	16.00	2507.00
RHC+	468	217.24	208.91	3.98	1556.28

Table A.9: Descriptive Statistics for Annual Patient Effective Dose from Standard CT Protocols Performed in 2020

Hospital 1

	N	Mean	STDEV	Min	Max
APC-	122	7.56	3.83	1.01	19.28
APC+	490	10.91	7.87	0.58	85.42
CAPC-	72	8.38	2.69	4.82	16.76
CAPC+	460	7.44	4.98	0.93	31.95
CC-	144	3.28	1.97	1.68	20.25
CC+	226	2.39	1.06	1.11	9.24
LS	296	18.94	9.75	5.59	85.30
PA	77	3.18	3.21	0.05	16.51
RCOL	146	5.56	3.14	2.43	21.63
RHC-	545	2.23	0.45	0.88	4.98
RHCC	104	3.34	1.16	2.01	7.57
RHC+	128	2.23	0.68	0.55	9.03

Hospital 2

	N	Mean	STDEV	Min	Max
APC-	206	10.51	7.06	0.03	52.42
APC+	1055	8.88	4.60	0.16	34.50
CAPC-	137	9.69	4.64	3.07	26.16
CAPC+	1090	9.75	5.43	0.96	43.62
CC-	247	6.01	2.98	0.02	30.07
CC+	461	6.04	2.36	1.47	14.99
LS	675	19.64	12.07	3.15	94.78
PA	286	4.84	4.08	0.03	16.31
RCOL	424	7.10	4.31	1.48	42.71
RHC-	738	2.68	0.66	0.01	13.98
RHCC	664	4.15	1.49	0.01	10.12
RHC+	157	2.74	0.90	1.85	13.23

Hospital 3

	N	Mean	STDEV	Min	Max
APC-	79	11.50	3.62	2.95	17.59
APC+	582	9.05	5.41	0.03	19.36
CAPC-	51	14.69	6.92	4.32	28.77
CAPC+	693	13.63	6.58	2.46	31.55
CC-	321	8.18	2.34	3.31	14.22
CC+	302	7.96	2.33	3.40	13.74
LS	278	15.00	7.21	3.65	36.56
PA	73	7.33	6.19	0.03	21.21
RCOL	168	9.24	3.03	3.10	15.17
RHC-	637	1.94	0.93	0.10	7.09
RHCC	31	3.19	2.03	0.27	5.37
RHC+	319	2.00	0.77	0.11	3.07

Hospital 4

	N	Mean	STDEV	Min	Max
APC-	367	14.62	10.94	0.06	70.48
APC+	2253	12.99	7.62	0.31	65.93
CAPC-	104	14.98	11.10	1.39	98.34
CAPC+	1045	11.97	8.42	0.12	62.64
CC-	403	4.41	3.94	0.07	39.84
CC+	404	3.48	2.05	0.67	22.51
LS	651	23.34	11.84	4.19	67.96
PA	992	7.11	6.12	0.03	39.72
RCOL	510	9.07	6.79	1.88	73.38
RHC-	2401	2.54	1.20	0.01	38.30
RHCC	419	3.73	1.31	0.51	7.60
RHC+	358	2.48	0.97	0.02	11.52

Hospital 5

	N	Mean	STDEV	Min	Max
APC-	98	10.84	5.57	3.32	44.29
APC+	817	11.31	4.53	1.64	41.96
CAPC-	118	10.37	2.71	5.04	20.90
CAPC+	1649	12.23	6.51	0.92	51.62
CC-	556	6.13	2.32	0.18	24.25
CC+	454	6.18	2.17	0.61	24.54
LS	710	18.72	11.41	4.68	72.23
PA	62	7.26	7.27	0.10	26.70
RCOL	235	10.89	5.90	4.32	76.34
RHC-	379	2.23	0.52	0.11	5.33
RHCC	144	3.51	1.18	1.15	5.21
RHC+	301	2.25	0.50	0.11	9.02

Hospital 6

	N	Mean	STDEV	Min	Max
APC-	294	8.35	6.91	0.01	60.45
APC+	2014	9.29	6.49	0.18	52.42
CAPC-	95	9.21	7.23	0.27	52.41
CAPC+	1543	9.63	6.57	1.22	63.63
CC-	704	4.90	3.26	0.04	42.04
CC+	693	4.42	2.28	1.29	20.93
LS	664	21.78	10.35	5.16	53.44
PA	484	4.32	4.55	0.03	28.11
RCOL	428	6.63	5.42	1.33	51.89
RHC-	1175	2.66	1.05	0.00	16.94
RHCC	323	3.90	1.31	2.00	6.73
RHC+	469	2.94	2.10	0.02	20.32

Table A.10: Descriptive Statistics for Annual Patient CTDIvol from Standard CT Protocols Performed in 2021

Hospital 1

	N	Mean	STDEV	Min	Max
APC-	64	12.16	10.69	4.20	67.50
APC+	429	10.24	7.23	2.70	67.40
CAPC-	53	8.54	4.93	3.10	32.80
CAPC+	368	6.87	4.82	2.09	43.54
CC-	93	4.65	2.43	1.70	14.10
CC+	210	3.87	2.08	1.20	13.00
LS	210	28.84	13.81	8.93	88.27
PA	42	8.24	4.49	3.17	22.05
RCOL	135	7.37	4.52	2.40	23.50
RHC-	435	54.55	2.39	38.08	56.01
RHCC	93	54.84	2.19	43.80	56.01
RHC+	84	54.92	2.51	43.80	56.01

Hospital 2

	N	Mean	STDEV	Min	Max
APC-	219	11.09	6.51	5.20	37.20
APC+	1044	10.48	6.37	5.20	46.52
CAPC-	364	9.69	5.14	3.47	27.40
CAPC+	828	9.86	5.01	4.19	34.77
CC-	208	9.78	4.77	3.10	23.00
CC+	361	9.28	4.58	3.00	22.70
LS	644	32.96	18.23	8.59	98.40
PA	169	11.64	8.83	2.97	104.29
RCOL	319	9.09	6.31	2.60	39.20
RHC-	560	58.47	2.20	38.10	69.60
RHCC	545	58.65	0.93	43.11	59.66
RHC+	186	58.52	1.71	41.23	58.70

Hospital 3

	N	Mean	STDEV	Min	Max
APC-	51	13.07	5.18	4.05	22.35
APC+	431	13.98	5.85	3.94	33.80
CAPC-	31	14.83	5.38	3.64	21.16
CAPC+	453	12.67	4.99	3.46	21.38
CC-	226	11.79	4.80	3.46	19.02
CC+	219	11.71	4.57	3.46	19.02
LS	247	23.67	11.30	5.84	39.44
PA	59	15.30	5.04	3.95	21.44
RCOL	147	14.94	5.40	3.70	24.20
RHC-	418	63.36	2.56	40.13	87.15
RHCC	110	63.11	2.48	37.99	65.57
RHC+	220	63.25	1.81	37.99	68.85

Hospital 4

	N	Mean	STDEV	Min	Max
APC-	236	18.54	11.54	4.60	65.07
APC+	1837	17.37	11.31	4.00	91.22
CAPC-	279	12.88	7.68	3.42	51.70
CAPC+	657	11.91	7.49	2.70	57.98
CC-	326	7.08	4.48	1.80	38.12
CC+	322	6.47	3.21	1.43	21.80
LS	560	43.73	20.44	4.20	119.72
PA	531	15.60	7.06	2.90	34.69
RCOL	2	9.85	3.89	7.10	12.60
RHC-	1982	61.00	3.28	36.78	79.58
RHCC	350	61.08	4.11	37.81	87.97
RHC+	285	58.29	7.95	29.32	87.97

Hospital 5

	N	Mean	STDEV	Min	Max
APC-	77	15.86	7.53	7.09	44.45
APC+	886	15.02	7.23	5.44	49.83
CAPC-	110	10.40	4.21	4.38	30.85
CAPC+	657	11.31	4.90	4.54	36.27
CC-	403	9.58	4.79	2.27	41.39
CC+	423	9.51	4.31	3.05	37.42
LS	560	29.62	17.56	7.68	106.25
PA	32	20.16	10.11	6.60	46.60
RCOL	225	15.00	7.83	5.20	43.91
RHC-	361	60.32	3.08	21.49	60.60
RHCC	96	60.60	0.00	60.60	60.60
RHC+	300	60.60	0.00	60.60	60.60

Hospital 6

	N	Mean	STDEV	Min	Max
APC-	231	9.70	6.53	4.10	40.30
APC+	1580	11.81	8.73	4.10	58.60
CAPC-	425	9.11	6.06	2.30	44.70
CAPC+	1113	9.18	6.21	3.01	55.61
CC-	487	7.41	4.06	2.30	31.30
CC+	550	7.33	4.63	1.70	40.60
LS	575	34.17	15.84	8.48	79.61
PA	288	10.22	6.61	1.98	34.41
RCOL	384	8.27	6.78	2.20	60.00
RHC-	997	60.65	3.58	36.60	74.32
RHCC	309	60.96	1.87	40.60	68.93
RHC+	340	60.34	4.02	38.08	61.52

Table A.11: Descriptive Statistics for Annual Patient Scan Length from Standard CT Protocols Performed in 2021

Hospital 1

	N	Mean	STDEV	Min	Max
APC-	64	500.87	66.13	243.38	807.41
APC+	429	516.08	51.68	283.09	989.72
CAPC-	53	699.52	43.87	556.45	795.61
CAPC+	368	922.58	64.58	506.82	1302.67
CC-	93	426.60	31.40	279.90	510.00
CC+	210	430.04	36.17	360.25	742.80
LS	210	248.96	20.14	224.93	299.04
PA	42	387.40	74.00	42.00	526.30
RCOL	135	501.44	36.72	433.61	606.58
RHC-	435	160.09	42.06	77.00	616.19
RHCC	93	260.35	70.30	150.99	376.00
RHC+	84	157.57	24.19	150.99	287.22

Hospital 2

	N	Mean	STDEV	Min	Max
APC-	219	595.40	182.80	228.80	1352.20
APC+	1044	564.63	67.46	298.14	1201.50
CAPC-	364	886.50	204.20	365.50	3243.80
CAPC+	828	951.41	97.84	365.54	1900.15
CC-	208	413.20	138.50	300.41	2215.76
CC+	361	405.79	54.66	280.23	891.31
LS	644	237.58	72.03	157.09	1097.69
PA	169	378.63	109.15	10.03	971.51
RCOL	319	561.21	133.08	406.39	1612.74
RHC-	560	196.38	51.54	59.71	671.81
RHCC	545	345.40	70.50	161.77	668.78
RHC+	186	188.52	28.50	156.76	388.55

Hospital 3

	N	Mean	STDEV	Min	Max
APC-	51	504.30	77.70	284.80	945.60
APC+	431	513.58	50.68	5.00	620.72
CAPC-	31	857.10	56.90	769.50	1038.60
CAPC+	453	856.62	44.30	693.21	979.04
CC-	226	365.20	27.79	301.93	442.16
CC+	219	366.81	30.34	285.66	441.32
LS	247	252.64	19.89	208.07	372.29
PA	59	408.42	53.88	68.45	530.56
RCOL	147	443.64	33.01	189.40	509.91
RHC-	421	149.58	27.21	62.12	402.62
RHCC	110	180.56	69.40	130.00	438.06
RHC+	220	146.17	19.90	130.00	414.13

Hospital 4

	N	Mean	STDEV	Min	Max
APC-	236	592.00	279.30	285.70	2508.40
APC+	1837	531.20	74.44	272.98	1116.28
CAPC-	279	840.62	128.92	466.51	1885.23
CAPC+	657	883.49	76.18	415.56	1394.67
CC-	326	394.77	126.56	265.91	1343.32
CC+	322	385.14	82.45	159.25	974.45
LS	560	206.91	43.41	114.03	543.08
PA	531	370.43	92.76	7.93	1440.36
RCOL	2	533.60	15.90	522.40	544.80
RHC-	1982	178.27	114.81	100.36	1737.58
RHCC	350	264.86	99.37	150.99	1438.20
RHC+	285	192.15	137.76	76.99	1438.20

Hospital 5

	N	Mean	STDEV	Min	Max
APC-	77	523.30	199.10	275.10	2141.10
APC+	887	509.41	51.42	261.65	816.60
CAPC-	110	685.63	97.18	443.17	1282.70
CAPC+	1188	853.42	53.92	320.32	1108.32
CC-	403	392.49	123.06	249.67	1125.56
CC+	423	362.10	62.76	260.47	1088.39
LS	560	250.83	22.43	147.29	398.54
PA	32	454.30	185.10	50.00	990.90
RCOL	225	528.70	157.10	242.70	1885.10
RHC-	361	160.29	63.63	119.99	597.40
RHCC	96	279.04	23.49	139.99	419.97
RHC+	300	140.52	10.55	89.99	279.98

Hospital 6

	N	Mean	STDEV	Min	Max
APC-	231	527.60	142.81	191.07	1658.09
APC+	1580	529.83	63.39	300.00	1183.75
CAPC-	425	860.72	112.92	510.70	1509.49
CAPC+	1113	894.86	80.04	510.70	1811.28
CC-	487	399.86	130.21	293.25	2071.96
CC+	550	387.61	42.95	204.08	799.45
LS	575	261.55	98.36	113.99	1135.76
PA	288	382.47	82.40	12.33	1095.85
RCOL	384	521.05	37.88	420.00	692.98
RHC-	997	202.68	157.86	77.00	1367.38
RHCC	309	284.00	156.00	150.99	1374.10
RHC+	340	233.30	251.90	151.00	1566.10

Table A.12: Descriptive Statistics for Annual Patient Effective Dose from Standard CT Protocols Performed in 2021

Hospital 1

	N	Mean	STDEV	Min	Max
APC-	64	8.92	8.04	3.45	50.56
APC+	429	11.46	8.58	2.73	85.35
CAPC-	53	8.58	4.19	3.20	30.63
CAPC+	368	9.72	5.87	2.91	66.25
CC-	93	3.27	1.44	1.79	9.48
CC+	210	2.42	0.98	1.10	6.00
LS	210	18.15	9.38	5.49	66.78
PA	42	5.53	2.85	2.55	14.57
RCOL	135	5.27	2.57	2.28	14.20
RHC-	435	2.30	1.29	1.06	27.28
RHCC	93	3.69	1.02	2.01	4.90
RHC+	84	2.24	0.23	1.83	3.24

Hospital 2

	N	Mean	STDEV	Min	Max
APC-	219	9.43	4.90	1.95	27.51
APC+	1044	8.71	4.75	2.84	75.56
CAPC-	364	11.95	5.11	3.83	34.62
CAPC+	828	13.29	5.86	4.35	78.49
CC-	208	6.51	2.60	2.24	18.91
CC+	361	6.16	2.55	2.52	22.54
LS	644	19.79	11.59	5.48	72.98
PA	169	7.45	3.49	0.35	19.14
RCOL	319	7.16	4.57	2.65	38.38
RHC-	560	2.79	0.58	0.90	7.50
RHCC	545	5.03	1.02	2.23	8.19
RHC+	186	2.79	0.88	2.23	13.39

Hospital 3

	N	Mean	STDEV	Min	Max
APC-	51	10.10	3.20	3.82	15.37
APC+	431	10.91	3.58	0.16	19.01
CAPC-	31	17.83	5.68	5.38	28.14
CAPC+	453	16.87	5.37	5.18	33.22
CC-	226	7.65	2.47	3.31	13.52
CC+	219	7.60	2.27	3.06	13.77
LS	247	14.97	7.34	3.57	28.46
PA	59	12.00	3.69	1.19	18.06
RCOL	147	9.71	3.00	3.07	16.29
RHC-	421	2.60	0.41	1.52	5.94
RHCC	110	3.15	1.13	2.27	7.22
RHC+	220	2.58	0.27	2.14	4.93

Hospital 4

	N	Mean	STDEV	Min	Max
APC-	236	16.04	11.01	4.28	75.74
APC+	1837	13.85	7.98	3.88	72.95
CAPC-	279	16.51	9.82	5.28	106.76
CAPC+	657	16.32	8.85	1.99	78.61
CC-	326	4.93	4.65	1.60	56.49
CC+	322	3.90	1.88	1.22	12.56
LS	560	23.40	11.91	3.71	93.25
PA	531	10.97	5.34	0.10	49.85
RCOL	2	8.00	2.47	6.26	9.75
RHC-	1982	2.71	1.40	0.86	29.65
RHCC	350	4.18	1.58	2.21	22.81
RHC+	285	2.91	2.61	0.57	29.39

Hospital 5

	N	Mean	STDEV	Min	Max
APC-	77	11.91	5.50	3.35	36.64
APC+	887	11.44	4.29	2.38	38.69
CAPC-	110	10.72	3.85	6.87	38.49
CAPC+	1188	15.33	4.81	6.51	45.51
CC-	403	6.23	2.21	3.59	20.88
CC+	423	6.08	1.95	2.88	20.53
LS	560	18.55	11.00	5.22	68.47
PA	32	15.31	8.51	2.08	43.85
RCOL	225	11.46	5.78	3.94	45.00
RHC-	361	2.51	0.88	1.91	9.96
RHCC	96	4.46	0.48	2.04	7.11
RHC+	300	2.25	0.19	1.65	4.08

Hospital 6

	N	Mean	STDEV	Min	Max
APC-	231	7.72	5.73	1.77	59.73
APC+	1580	9.28	5.85	2.36	45.95
CAPC-	425	11.69	6.27	3.71	52.84
CAPC+	1113	12.37	6.72	4.81	72.50
CC-	487	5.23	4.04	1.80	59.49
CC+	550	4.42	2.29	1.52	25.49
LS	575	21.54	10.08	4.45	68.30
PA	288	6.87	4.41	0.68	28.76
RCOL	384	6.34	4.43	2.10	43.00
RHC-	997	2.84	1.33	1.16	16.48
RHCC	309	4.33	1.71	2.00	14.77
RHC+	340	3.31	2.79	2.00	20.97

Table A.13: Tukey Simultaneous Test for Difference in CTDIvol Means for Standard CT Protocols Preformed in 2018

APC-

	T-Value	P-Value
H2- H1	1.99	0.35
H3- H1	5.61	0.00
H4- H1	2.14	0.27
H5- H1	8.21	0.00
H6- H1	0.54	1.00
H3- H2	4.66	0.00
H4- H2	0.14	1.00
H5- H2	7.75	0.00
H6- H2	-1.84	0.44
H4- H3	-4.65	0.00
H5- H3	0.91	0.95
H6- H3	-5.85	0.00
H5- H4	7.86	0.00
H6- H4	-2.05	0.31
H5- H6	-9.40	0.00

APC+

	T-Value	P-Value
H2- H1	2.18	0.25
H3- H1	8.89	0.00
H4- H1	5.40	0.00
H5- H1	9.49	0.00
H6- H1	4.71	0.00
H3- H2	8.46	0.00
H4- H2	4.31	0.00
H5- H2	9.56	0.00
H6- H2	3.36	0.01
H4- H3	-5.74	0.00
H5- H3	-0.86	0.96
H6- H3	-6.57	0.00
H5- H4	6.24	0.00
H6- H4	-1.19	0.84
H5- H6	-7.38	0.00

CAPC-

	T-Value	P-Value
H2- H1	2.12	0.28
H3- H1	3.72	0.00
H4- H1	3.03	0.03
H5- H1	3.64	0.00
H6- H1	2.09	0.30
H3- H2	2.36	0.17
H4- H2	1.20	0.84
H5- H2	1.61	0.59
H6- H2	0.14	1.00
H4- H3	-1.43	0.71
H5- H3	-1.43	0.71
H6- H3	-2.17	0.25
H5- H4	0.16	1.00
H6- H4	-0.98	0.93
H5- H6	-1.29	0.79

CAPC+

	T-Value	P-Value
H2- H1	5.85	0.00
H3- H1	15.21	0.00
H4- H1	4.53	0.00
H5- H1	11.64	0.00
H6- H1	5.31	0.00
H3- H2	13.01	0.00
H4- H2	-1.28	0.79
H5- H2	8.30	0.00
H6- H2	-0.76	0.97
H4- H3	-12.99	0.00
H5- H3	-7.19	0.00
H6- H3	-13.61	0.00
H5- H4	8.53	0.00
H6- H4	0.61	0.99
H5- H6	-9.10	0.00

CC-

	T-Value	P-Value
H2- H1	10.30	0.00
H3- H1	18.84	0.00
H4- H1	1.27	0.80
H5- H1	13.77	0.00
H6- H1	8.25	0.00
H3- H2	10.89	0.00
H4- H2	-11.75	0.00
H5- H2	3.30	0.01
H6- H2	-4.04	0.00
H4- H3	-22.65	0.00
H5- H3	-9.51	0.00
H6- H3	-16.49	0.00
H5- H4	17.40	0.00
H6- H4	9.61	0.00
H5- H6	-9.24	0.00

CC+

	T-Value	P-Value
H2- H1	14.05	0.00
H3- H1	20.01	0.00
H4- H1	0.90	0.95
H5- H1	14.61	0.00
H6- H1	9.49	0.00
H3- H2	9.12	0.00
H4- H2	-16.76	0.00
H5- H2	1.36	0.75
H6- H2	-7.31	0.00
H4- H3	-23.62	0.00
H5- H3	-7.46	0.00
H6- H3	-16.00	0.00
H5- H4	17.18	0.00
H6- H4	11.11	0.00
H5- H6	-8.25	0.00

L Spine

	T-Value	P-Value
H2- H1	0.62	0.99
H3- H1	-4.35	0.00
H4- H1	0.45	1.00
H5- H1	7.13	0.00
H6- H1	0.02	1.00
H3- H2	-5.76	0.00
H4- H2	-0.11	1.00
H5- H2	8.78	0.00
H6- H2	-0.71	0.98
H4- H3	4.98	0.00
H5- H3	12.44	0.00
H6- H3	4.85	0.00
H5- H4	7.05	0.00
H6- H4	-0.49	1.00
H5- H6	-8.54	0.00

PA

	T-Value	P-Value
H2- H1	-0.10	1.00
H3- H1	5.06	0.00
H4- H1	-0.85	0.96
H5- H1	5.44	0.00
H6- H1	-0.94	0.94
H3- H2	6.87	0.00
H4- H2	-1.36	0.75
H5- H2	8.08	0.00
H6- H2	-1.44	0.70
H4- H3	-8.34	0.00
H5- H3	-0.16	1.00
H6- H3	-8.16	0.00
H5- H4	10.30	0.00
H6- H4	-0.25	1.00
H5- H6	-9.87	0.00

RCOL

	T-Value	P-Value
H2- H1	2.55	0.11
H3- H1	9.36	0.00
H4- H1	2.13	0.27
H5- H1	10.63	0.00
H6- H1	1.10	0.88
H3- H2	8.67	0.00
H4- H2	-0.61	0.99
H5- H2	10.72	0.00
H6- H2	-1.84	0.44
H4- H3	-9.17	0.00
H5- H3	-0.64	0.99
H6- H3	-9.82	0.00
H5- H4	11.47	0.00
H6- H4	-1.29	0.79
H5- H6	-12.09	0.00

RHC-

	T-Value	P-Value
H2- H1	25.12	0.00
H3- H1	51.00	0.00
H4- H1	47.93	0.00
H5- H1	34.01	0.00
H6- H1	34.28	0.00
H3- H2	30.25	0.00
H4- H2	21.32	0.00
H5- H2	10.94	0.00
H6- H2	7.23	0.00
H4- H3	-16.73	0.00
H5- H3	-18.90	0.00
H6- H3	-27.14	0.00
H5- H4	-6.71	0.00
H6- H4	-16.66	0.00
H5- H6	-5.52	0.00

RHCC

	T-Value	P-Value
H2- H1	15.85	0.00
H3- H1	24.42	0.00
H4- H1	26.40	0.00
H5- H1	22.26	0.00
H6- H1	18.73	0.00
H3- H2	17.74	0.00
H4- H2	24.35	0.00
H5- H2	14.56	0.00
H6- H2	7.84	0.00
H4- H3	-7.71	0.00
H5- H3	-9.40	0.00
H6- H3	-14.37	0.00
H5- H4	-3.82	0.00
H6- H4	-14.60	0.00
H5- H6	-8.02	0.00

RHC+

	T-Value	P-Value
H2- H1	6.36	0.00
H3- H1	22.03	0.00
H4- H1	9.76	0.00
H5- H1	14.31	0.00
H6- H1	12.43	0.00
H3- H2	12.93	0.00
H4- H2	1.46	0.69
H5- H2	5.81	0.00
H6- H2	3.53	0.01
H4- H3	-16.36	0.00
H5- H3	-9.77	0.00
H6- H3	-14.70	0.00
H5- H4	6.26	0.00
H6- H4	3.07	0.03
H5- H6	-3.82	0.00

Table A.14: Tukey Simultaneous Test for Difference in Scan Length Means for Standard CT Protocols Preformed in 2018

APC-

	T-Value	P-Value
H2- H1	5.51	0.00
H3- H1	-1.68	0.55
H4- H1	1.09	0.89
H5- H1	1.87	0.42
H6- H1	1.68	0.55
H3- H2	-6.36	0.00
H4- H2	-5.86	0.00
H5- H2	-3.91	0.00
H6- H2	-4.89	0.00
H4- H3	2.78	0.06
H5- H3	3.34	0.01
H6- H3	3.24	0.02
H5- H4	1.12	0.87
H6- H4	0.81	0.97
H5- H6	-0.40	1.00

APC+

	T-Value	P-Value
H2- H1	14.22	0.00
H3- H1	4.38	0.00
H4- H1	4.97	0.00
H5- H1	8.31	0.00
H6- H1	0.95	0.93
H3- H2	-8.76	0.00
H4- H2	-13.60	0.00
H5- H2	-6.93	0.00
H6- H2	-19.69	0.00
H4- H3	-0.56	0.99
H5- H3	3.16	0.02
H6- H3	-4.58	0.00
H5- H4	5.17	0.00
H6- H4	-6.31	0.00
H5- H6	-10.55	0.00

CAPC-

	T-Value	P-Value
H2- H1	3.34	0.01
H3- H1	6.64	0.00
H4- H1	1.07	0.89
H5- H1	11.62	0.00
H6- H1	-1.58	0.61
H3- H2	4.55	0.00
H4- H2	-2.25	0.22
H5- H2	9.41	0.00
H6- H2	-5.23	0.00
H4- H3	-5.91	0.00
H5- H3	1.18	0.85
H6- H3	-7.98	0.00
H5- H4	10.77	0.00
H6- H4	-2.72	0.07
H5- H6	-13.98	0.00

CAPC+

	T-Value	P-Value
H2- H1	6.25	0.00
H3- H1	-7.59	0.00
H4- H1	-2.27	0.21
H5- H1	-4.02	0.00
H6- H1	-5.19	0.00
H3- H2	-17.48	0.00
H4- H2	-10.93	0.00
H5- H2	-15.93	0.00
H6- H2	-16.28	0.00
H4- H3	6.47	0.00
H5- H3	5.78	0.00
H6- H3	3.75	0.00
H5- H4	-1.92	0.39
H6- H4	-3.48	0.01
H5- H6	-2.14	0.27

CC-

	T-Value	P-Value
H2- H1	-1.88	0.42
H3- H1	-7.61	0.00
H4- H1	-2.51	0.12
H5- H1	-5.73	0.00
H6- H1	-4.42	0.00
H3- H2	-7.22	0.00
H4- H2	-0.77	0.97
H5- H2	-4.95	0.00
H6- H2	-3.18	0.02
H4- H3	6.66	0.00
H5- H3	3.64	0.00
H6- H3	5.26	0.00
H5- H4	-4.23	0.00
H6- H4	-2.40	0.16
H5- H6	2.17	0.25

CC+

	T-Value	P-Value
H2- H1	-1.21	0.83
H3- H1	-8.36	0.00
H4- H1	-5.28	0.00
H5- H1	-6.98	0.00
H6- H1	-4.63	0.00
H3- H2	-9.72	0.00
H4- H2	-5.60	0.00
H5- H2	-8.02	0.00
H6- H2	-4.97	0.00
H4- H3	3.83	0.00
H5- H3	2.02	0.33
H6- H3	5.83	0.00
H5- H4	-1.97	0.36
H6- H4	1.46	0.69
H5- H6	3.82	0.00

L Spine

	T-Value	P-Value
H2- H1	-6.42	0.00
H3- H1	2.46	0.14
H4- H1	-7.57	0.00
H5- H1	1.62	0.59
H6- H1	2.09	0.29
H3- H2	9.25	0.00
H4- H2	-2.33	0.18
H5- H2	11.38	0.00
H6- H2	10.16	0.00
H4- H3	-10.06	0.00
H5- H3	-1.48	0.68
H6- H3	-0.68	0.99
H5- H4	11.46	0.00
H6- H4	10.73	0.00
H5- H6	0.87	0.95

PA

	T-Value	P-Value
H2- H1	0.29	1.00
H3- H1	0.79	0.97
H4- H1	-1.36	0.75
H5- H1	-0.42	1.00
H6- H1	-1.27	0.80
H3- H2	0.73	0.98
H4- H2	-3.04	0.03
H5- H2	-1.00	0.92
H6- H2	-2.68	0.08
H4- H3	-2.71	0.07
H5- H3	-1.43	0.71
H6- H3	-2.55	0.11
H5- H4	1.28	0.80
H6- H4	0.11	1.00
H5- H6	-1.13	0.87

RCOL

	T-Value	P-Value
H2- H1	7.26	0.00
H3- H1	-5.08	0.00
H4- H1	1.42	0.72
H5- H1	3.53	0.01
H6- H1	0.25	1.00
H3- H2	-12.98	0.00
H4- H2	-8.03	0.00
H5- H2	-4.65	0.00
H6- H2	-9.05	0.00
H4- H3	7.44	0.00
H5- H3	9.25	0.00
H6- H3	6.14	0.00
H5- H4	2.89	0.04
H6- H4	-1.51	0.66
H5- H6	-4.16	0.00

RHC-

	T-Value	P-Value
H2- H1	6.39	0.00
H3- H1	-3.91	0.00
H4- H1	3.08	0.03
H5- H1	4.11	0.00
H6- H1	7.08	0.00
H3- H2	-10.57	0.00
H4- H2	-5.00	0.00
H5- H2	-2.16	0.26
H6- H2	0.00	1.00
H4- H3	7.97	0.00
H5- H3	8.13	0.00
H6- H3	11.71	0.00
H5- H4	2.06	0.31
H6- H4	6.12	0.00
H5- H6	2.41	0.15

RHCC

	T-Value	P-Value
H2- H1	7.39	0.00
H3- H1	-1.87	0.42
H4- H1	-0.78	0.97
H5- H1	3.59	0.01
H6- H1	4.37	0.00
H3- H2	-8.39	0.00
H4- H2	-16.75	0.00
H5- H2	-5.30	0.00
H6- H2	-6.12	0.00
H4- H3	1.62	0.59
H5- H3	5.20	0.00
H6- H3	5.91	0.00
H5- H4	6.81	0.00
H6- H4	9.45	0.00
H5- H6	0.74	0.98

RHC+

	T-Value	P-Value
H2- H1	3.32	0.01
H3- H1	-1.54	0.64
H4- H1	1.28	0.80
H5- H1	1.61	0.59
H6- H1	6.32	0.00
H3- H2	-5.18	0.00
H4- H2	-2.71	0.07
H5- H2	-2.32	0.19
H6- H2	1.69	0.54
H4- H3	3.62	0.00
H5- H3	3.93	0.00
H6- H3	10.34	0.00
H5- H4	0.48	1.00
H6- H4	6.88	0.00
H5- H6	6.02	0.00

Table A.15: Tukey Simultaneous Test for Difference in Effective Dose Means for Standard CT Protocols Preformed in 2018

APC-

	T-Value	P-Value
H2- H1	3.71	0.00
H3- H1	4.53	0.00
H4- H1	2.45	0.14
H5- H1	8.86	0.00
H6- H1	1.23	0.82
H3- H2	2.05	0.31
H4- H2	-1.73	0.51
H5- H2	6.60	0.00
H6- H2	-3.16	0.02
H4- H3	-3.17	0.02
H5- H3	2.59	0.10
H6- H3	-4.08	0.00
H5- H4	8.32	0.00
H6- H4	-1.55	0.63
H5- H6	-9.42	0.00

APC+

	T-Value	P-Value
H2- H1	-5.99	0.00
H3- H1	2.38	0.16
H4- H1	-3.93	0.00
H5- H1	2.56	0.11
H6- H1	-6.13	0.00
H3- H2	8.73	0.00
H4- H2	3.20	0.02
H5- H2	10.77	0.00
H6- H2	0.30	1.00
H4- H3	-6.82	0.00
H5- H3	-0.21	1.00
H6- H3	-9.01	0.00
H5- H4	8.56	0.00
H6- H4	-3.30	0.01
H5- H6	-11.51	0.00

CAPC-

	T-Value	P-Value
H2- H1	2.76	0.06
H3- H1	8.36	0.00
H4- H1	2.35	0.17
H5- H1	9.21	0.00
H6- H1	1.30	0.78
H3- H2	6.82	0.00
H4- H2	-0.23	1.00
H5- H2	7.32	0.00
H6- H2	-1.41	0.72
H4- H3	-6.66	0.00
H5- H3	-2.47	0.13
H6- H3	-7.49	0.00
H5- H4	6.75	0.00
H6- H4	-1.08	0.89
H5- H6	-8.04	0.00

CAPC+

	T-Value	P-Value
H2- H1	8.53	0.00
H3- H1	18.89	0.00
H4- H1	6.31	0.00
H5- H1	15.40	0.00
H6- H1	6.48	0.00
H3- H2	14.63	0.00
H4- H2	-2.25	0.22
H5- H2	9.73	0.00
H6- H2	-2.88	0.05
H4- H3	-15.30	0.00
H5- H3	-7.77	0.00
H6- H3	-17.00	0.00
H5- H4	10.80	0.00
H6- H4	-0.31	1.00
H5- H6	-12.86	0.00

CC-

	T-Value	P-Value
H2- H1	11.33	0.00
H3- H1	19.81	0.00
H4- H1	1.26	0.81
H5- H1	13.34	0.00
H6- H1	8.41	0.00
H3- H2	10.83	0.00
H4- H2	-13.10	0.00
H5- H2	1.18	0.85
H6- H2	-5.34	0.00
H4- H3	-23.91	0.00
H5- H3	-11.50	0.00
H6- H3	-17.68	0.00
H5- H4	16.81	0.00
H6- H4	9.85	0.00
H5- H6	-8.24	0.00

CC+

	T-Value	P-Value
H2- H1	18.72	0.00
H3- H1	24.98	0.00
H4- H1	1.01	0.91
H5- H1	18.08	0.00
H6- H1	10.90	0.00
H3- H2	9.90	0.00
H4- H2	-22.57	0.00
H5- H2	-0.09	1.00
H6- H2	-12.31	0.00
H4- H3	-29.62	0.00
H5- H3	-9.51	0.00
H6- H3	-21.22	0.00
H5- H4	21.39	0.00
H6- H4	12.77	0.00
H5- H6	-11.39	0.00

L Spine

	T-Value	P-Value
H2- H1	-1.53	0.65
H3- H1	-3.97	0.00
H4- H1	-2.92	0.04
H5- H1	6.60	0.00
H6- H1	0.12	1.00
H3- H2	-3.19	0.02
H4- H2	-1.92	0.39
H5- H2	11.13	0.00
H6- H2	1.94	0.38
H4- H3	1.25	0.81
H5- H3	11.46	0.00
H6- H3	4.54	0.00
H5- H4	10.83	0.00
H6- H4	3.42	0.01
H5- H6	-7.77	0.00

PA

	T-Value	P-Value
H2- H1	1.82	0.45
H3- H1	8.01	0.00
H4- H1	0.47	1.00
H5- H1	7.60	0.00
H6- H1	-0.02	1.00
H3- H2	8.63	0.00
H4- H2	-2.70	0.08
H5- H2	8.63	0.00
H6- H2	-3.28	0.01
H4- H3	-11.10	0.00
H5- H3	-1.36	0.75
H6- H3	-11.23	0.00
H5- H4	11.98	0.00
H6- H4	-1.04	0.90
H5- H6	-11.97	0.00

RCOL

	T-Value	P-Value
H2- H1	4.35	0.00
H3- H1	8.32	0.00
H4- H1	2.85	0.05
H5- H1	13.39	0.00
H6- H1	1.58	0.62
H3- H2	5.71	0.00
H4- H2	-2.09	0.29
H5- H2	12.06	0.00
H6- H2	-3.54	0.01
H4- H3	-7.24	0.00
H5- H3	3.21	0.02
H6- H3	-8.16	0.00
H5- H4	14.24	0.00
H6- H4	-1.59	0.61
H5- H6	-14.99	0.00

RHC-

	T-Value	P-Value
H2- H1	9.24	0.00
H3- H1	1.86	0.43
H4- H1	7.57	0.00
H5- H1	8.59	0.00
H6- H1	10.08	0.00
H3- H2	-7.17	0.00
H4- H2	-3.67	0.00
H5- H2	-0.24	1.00
H6- H2	-0.19	1.00
H4- H3	5.16	0.00
H5- H3	6.62	0.00
H6- H3	7.77	0.00
H5- H4	3.10	0.02
H6- H4	4.25	0.00
H5- H6	0.10	1.00

RHCC

	T-Value	P-Value
H2- H1	6.67	0.00
H3- H1	1.69	0.54
H4- H1	2.44	0.14
H5- H1	6.21	0.00
H6- H1	5.03	0.00
H3- H2	-3.33	0.01
H4- H2	-8.38	0.00
H5- H2	0.50	1.00
H6- H2	-3.09	0.02
H4- H3	-0.03	1.00
H5- H3	3.30	0.01
H6- H3	2.10	0.29
H5- H4	6.22	0.00
H6- H4	4.70	0.00
H5- H6	-2.52	0.12

RHC+

	T-Value	P-Value
H2- H1	3.89	0.00
H3- H1	1.25	0.81
H4- H1	2.48	0.13
H5- H1	3.46	0.01
H6- H1	4.60	0.00
H3- H2	-3.28	0.01
H4- H2	-2.28	0.20
H5- H2	-1.28	0.80
H6- H2	-0.54	0.99
H4- H3	1.49	0.67
H5- H3	2.74	0.07
H6- H3	4.22	0.00
H5- H4	1.37	0.75
H6- H4	2.79	0.06
H5- H6	1.18	0.85

A.16 Tukey Simultaneous Test for Difference in CTDIvol Means for Abdomen Pelvis Protocols without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	0.67	0.91
20- 18	1.39	0.50
21- 18	3.07	0.01
20-19	0.73	0.89
21- 19	2.48	0.06
21- 20	1.82	0.26

Hospital 2

Year	T-Value	P-Value
19- 18	1.86	0.25
20- 18	3.31	0.01
21- 18	0.76	0.87
20-19	1.50	0.44
21- 19	-0.89	0.81
21- 20	-2.25	0.11

Hospital 3

Year	T-Value	P-Value
19- 18	0.24	1.00
20- 18	1.32	0.55
21- 18	-1.40	0.50
20-19	0.92	0.80
21- 19	-1.45	0.47
21- 20	-2.41	0.08

Hospital 4

Year	T-Value	P-Value
19- 18	1.22	0.61
20- 18	10.10	0.00
21- 18	9.26	0.00
20-19	8.59	0.00
21- 19	8.00	0.00
21- 20	0.43	0.97

Hospital 5

Year	T-Value	P-Value
19- 18	-1.10	0.69
20- 18	-1.47	0.46
21- 18	0.68	0.90
20-19	-0.33	0.99
21- 19	1.43	0.48
21- 20	1.72	0.32

Hospital 6

Year	T-Value	P-Value
19- 18	0.03	1.00
20- 18	2.40	0.08
21- 18	0.08	1.00
20-19	2.08	0.16
21- 19	0.05	1.00
21- 20	-2.00	0.19

A.17 Tukey Simultaneous Test for Difference in Scan Length Means for Abdomen Pelvis Protocols without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.28	0.99
20- 18	0.90	0.80
21- 18	-0.61	0.93
20-19	1.11	0.69
21- 19	-0.39	0.98
21- 20	-1.25	0.59

Hospital 2

Year	T-Value	P-Value
19- 18	0.80	0.86
20- 18	2.08	0.16
21- 18	1.10	0.69
20-19	1.26	0.59
21- 19	0.33	0.99
21- 20	-0.88	0.82

Hospital 3

Year	T-Value	P-Value
19- 18	1.43	0.48
20- 18	0.98	0.76
21- 18	1.35	0.53
20-19	-0.49	0.96
21- 19	0.00	1.00
21- 20	0.47	0.97

Hospital 4

Year	T-Value	P-Value
19- 18	2.78	0.03
20- 18	0.82	0.84
21- 18	3.70	0.00
20-19	-1.79	0.28
21- 19	1.32	0.55
21- 20	2.83	0.02

Hospital 5

Year	T-Value	P-Value
19- 18	-1.43	0.48
20- 18	-1.02	0.74
21- 18	-0.77	0.87
20-19	0.32	0.99
21- 19	0.43	0.97
21- 20	0.13	1.00

Hospital 6

Year	T-Value	P-Value
19- 18	1.02	0.74
20- 18	-0.61	0.93
21- 18	-0.37	0.98
20-19	-1.49	0.45
21- 19	-1.22	0.61
21- 20	0.19	1.00

A.18 Tukey Simultaneous Test for Difference in Effective Dose Means for Abdomen Pelvis Protocols without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	0.62	0.93
20- 18	1.12	0.68
21- 18	2.91	0.02
20-19	0.51	0.96
21- 19	2.37	0.08
21- 20	1.89	0.23

Hospital 2

Year	T-Value	P-Value
19- 18	1.89	0.23
20- 18	3.40	0.00
21- 18	1.20	0.63
20-19	1.55	0.41
21- 19	-0.52	0.96
21- 20	-1.95	0.21

Hospital 3

Year	T-Value	P-Value
19- 18	1.57	0.40
20- 18	2.65	0.04
21- 18	-0.14	1.00
20-19	0.82	0.85
21- 19	-1.45	0.47
21- 20	-2.32	0.09

Hospital 4

Year	T-Value	P-Value
19- 18	2.56	0.05
20- 18	9.65	0.00
21- 18	10.27	0.00
20-19	6.92	0.00
21- 19	7.89	0.00
21- 20	1.76	0.29

Hospital 5

Year	T-Value	P-Value
19- 18	-1.56	0.40
20- 18	-1.62	0.37
21- 18	0.00	1.00
20-19	-0.08	1.00
21- 19	1.20	0.63
21- 20	1.25	0.59

Hospital 6

Year	T-Value	P-Value
19- 18	1.06	0.71
20- 18	1.51	0.43
21- 18	0.25	0.99
20-19	0.34	0.99
21- 19	-0.71	0.90
21- 20	-1.07	0.71

A.19 Tukey Simultaneous Test for Difference in CTDIvol Means for Abdomen Pelvis Protocols with Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.37	0.98
20- 18	-0.02	1.00
21- 18	0.94	0.78
20-19	0.35	0.99
21- 19	1.29	0.57
21- 20	0.95	0.78

Hospital 2

Year	T-Value	P-Value
19- 18	0.43	0.97
20- 18	0.52	0.95
21- 18	-1.07	0.71
20-19	0.12	1.00
21- 19	-1.49	0.44
21- 20	-1.52	0.43

Hospital 3

Year	T-Value	P-Value
19- 18	-0.81	0.85
20- 18	4.82	0.00
21- 18	-1.24	0.60
20-19	5.94	0.00
21- 19	-0.52	0.96
21- 20	-5.99	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	-0.08	1.00
20- 18	13.18	0.00
21- 18	15.63	0.00
20-19	14.47	0.00
21- 19	16.99	0.00
21- 20	3.24	0.01

Hospital 5

Year	T-Value	P-Value
19- 18	1.82	0.27
20- 18	1.64	0.35
21- 18	2.82	0.02
20-19	-0.21	1.00
21- 19	0.85	0.83
21- 20	1.09	0.69

Hospital 6

Year	T-Value	P-Value
19- 18	1.52	0.43
20- 18	0.33	0.99
21- 18	0.15	1.00
20-19	-1.18	0.64
21- 19	-1.27	0.58
21- 20	-0.16	1.00

A.20 Tukey Simultaneous Test for Difference in Scan Length Means for Abdomen Pelvis Protocols with Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.54	0.95
20- 18	1.99	0.19
21- 18	2.39	0.08
20-19	2.52	0.06
21- 19	2.90	0.02
21- 20	0.47	0.97

Hospital 2

Year	T-Value	P-Value
19- 18	0.41	0.98
20- 18	-0.38	0.98
21- 18	2.92	0.02
20-19	-0.77	0.87
21- 19	2.58	0.05
21- 20	3.16	0.01

Hospital 3

Year	T-Value	P-Value
19- 18	-1.32	0.55
20- 18	-13.78	0.00
21- 18	-0.94	0.79
20-19	-13.16	0.00
21- 19	0.30	0.99
21- 20	12.43	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	-1.63	0.36
20- 18	2.41	0.07
21- 18	3.65	0.00
20-19	4.37	0.00
21- 19	5.59	0.00
21- 20	1.43	0.48

Hospital 5

Year	T-Value	P-Value
19- 18	-1.93	0.22
20- 18	-3.32	0.01
21- 18	-5.82	0.00
20-19	-1.25	0.60
21- 19	-3.53	0.00
21- 20	-2.32	0.09

Hospital 6

Year	T-Value	P-Value
19- 18	6.26	0.00
20- 18	6.89	0.00
21- 18	7.41	0.00
20-19	0.69	0.90
21- 19	1.61	0.37
21- 20	0.95	0.78

A.21 Tukey Simultaneous Test for Difference in Effective Dose Means for Abdomen Pelvis Protocols with Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.30	0.99
20- 18	0.63	0.92
21- 18	1.70	0.33
20-19	0.92	0.79
21- 19	1.98	0.20
21- 20	1.09	0.70

Hospital 2

Year	T-Value	P-Value
19- 18	0.53	0.95
20- 18	0.51	0.96
21- 18	-0.37	0.98
20-19	0.01	1.00
21- 19	-0.88	0.82
21- 20	-0.84	0.84

Hospital 3

Year	T-Value	P-Value
19- 18	-1.43	0.48
20- 18	-9.34	0.00
21- 18	-2.02	0.18
20-19	-8.34	0.00
21- 19	-0.72	0.89
21- 20	6.97	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	-0.45	0.97
20- 18	15.49	0.00
21- 18	18.32	0.00
20-19	17.39	0.00
21- 19	20.29	0.00
21- 20	3.76	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	0.58	0.94
20- 18	-0.44	0.97
21- 18	0.17	1.00
20-19	-0.97	0.77
21- 19	-0.41	0.98
21- 20	0.59	0.94

Hospital 6

Year	T-Value	P-Value
19- 18	3.54	0.00
20- 18	2.28	0.10
21- 18	2.05	0.17
20-19	-1.24	0.60
21- 19	-1.24	0.60
21- 20	-0.08	1.00

A.22 Tukey Simultaneous Test for Difference in CTDIvol Means for Chest Abdomen Pelvis Protocols without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.41	0.98
20- 18	-1.47	0.46
21- 18	-0.60	0.93
20-19	-1.10	0.69
21- 19	-0.21	1.00
21- 20	0.85	0.83

Hospital 2

Year	T-Value	P-Value
19- 18	0.81	0.85
20- 18	0.36	0.98
21- 18	0.92	0.80
20-19	-0.46	0.97
21- 19	-0.03	1.00
21- 20	0.52	0.95

Hospital 3

Year	T-Value	P-Value
19- 18	2.39	0.08
20- 18	0.68	0.90
21- 18	2.48	0.07
20-19	-1.95	0.21
21- 19	0.44	0.97
21- 20	2.07	0.17

Hospital 4

Year	T-Value	P-Value
19- 18	-0.18	1.00
20- 18	3.47	0.00
21- 18	2.94	0.02
20-19	4.05	0.00
21- 19	3.65	0.00
21- 20	-1.25	0.59

Hospital 5

Year	T-Value	P-Value
19- 18	-1.32	0.55
20- 18	-0.19	1.00
21- 18	0.47	0.97
20-19	1.04	0.72
21- 19	1.64	0.36
21- 20	0.60	0.93

Hospital 6

Year	T-Value	P-Value
19- 18	-1.47	0.45
20- 18	-0.08	1.00
21- 18	-0.24	1.00
20-19	1.46	0.46
21- 19	1.69	0.33
21- 20	-0.15	1.00

A.23 Tukey Simultaneous Test for Difference in Scan Length Means for Chest Abdomen Pelvis Protocols without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.17	1.00
20- 18	-17.76	0.00
21- 18	3.06	0.01
20-19	-18.43	0.00
21- 19	3.37	0.00
21- 20	21.48	0.00

Hospital 2

Year	T-Value	P-Value
19- 18	1.10	0.69
20- 18	-0.96	0.77
21- 18	6.97	0.00
20-19	-2.16	0.13
21- 19	6.10	0.00
21- 20	8.63	0.00

Hospital 3

Year	T-Value	P-Value
19- 18	-0.18	1.00
20- 18	-5.75	0.00
21- 18	0.54	0.95
20-19	-6.53	0.00
21- 19	0.79	0.86
21- 20	6.28	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	1.43	0.48
20- 18	0.01	1.00
21- 18	5.14	0.00
20-19	-1.52	0.42
21- 19	4.08	0.00
21- 20	5.66	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	-10.12	0.00
20- 18	-11.60	0.00
21- 18	-10.35	0.00
20-19	-1.52	0.43
21- 19	-0.54	0.95
21- 20	0.94	0.79

Hospital 6

Year	T-Value	P-Value
19- 18	0.89	0.81
20- 18	-0.33	0.99
21- 18	12.04	0.00
20-19	-1.25	0.60
21- 19	11.12	0.00
21- 20	13.29	0.00

A.24 Tukey Simultaneous Test for Difference in Effective Dose Means for Chest Abdomen Pelvis Protocols without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	0.01	1.00
20- 18	-5.18	0.00
21- 18	0.91	0.80
20-19	-5.45	0.00
21- 19	0.93	0.79
21- 20	6.28	0.00

Hospital 2

Year	T-Value	P-Value
19- 18	1.02	0.74
20- 18	-0.22	1.00
21- 18	4.12	0.00
20-19	-1.31	0.56
21- 19	3.13	0.01
21- 20	4.66	0.00

Hospital 3

Year	T-Value	P-Value
19- 18	1.43	0.48
20- 18	-1.13	0.67
21- 18	1.03	0.73
20-19	-2.97	0.02
21- 19	-0.25	1.00
21- 20	2.26	0.11

Hospital 4

Year	T-Value	P-Value
19- 18	0.80	0.85
20- 18	3.80	0.00
21- 18	5.74	0.00
20-19	3.36	0.00
21- 19	5.61	0.00
21- 20	1.42	0.49

Hospital 5

Year	T-Value	P-Value
19- 18	-9.50	0.00
20- 18	-8.02	0.00
21- 18	-7.10	0.00
20-19	1.25	0.59
21- 19	1.94	0.21
21- 20	0.70	0.90

Hospital 6

Year	T-Value	P-Value
19- 18	-1.26	0.59
20- 18	0.38	0.98
21- 18	3.83	0.00
20-19	1.69	0.33
21- 19	5.55	0.00
21- 20	3.58	0.00

A.25 Tukey Simultaneous Test for Difference in CTDIvol Means for Chest Abdomen Pelvis Protocols with Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.90	0.81
20- 18	-1.70	0.33
21- 18	-0.95	0.78
20-19	-0.79	0.86
21- 19	-0.05	1.00
21- 20	0.73	0.88

Hospital 2

Year	T-Value	P-Value
19- 18	-1.12	0.68
20- 18	1.14	0.67
21- 18	3.01	0.01
20-19	2.31	0.10
21- 19	4.14	0.00
21- 20	2.00	0.19

Hospital 3

Year	T-Value	P-Value
19- 18	-0.04	1.00
20- 18	0.06	1.00
21- 18	-0.75	0.88
20-19	0.10	1.00
21- 19	-0.70	0.90
21- 20	-0.85	0.83

Hospital 4

Year	T-Value	P-Value
19- 18	-2.10	0.15
20- 18	5.28	0.00
21- 18	7.82	0.00
20-19	7.95	0.00
21- 19	10.31	0.00
21- 20	3.43	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	1.61	0.37
20- 18	1.46	0.46
21- 18	1.54	0.41
20-19	-0.24	1.00
21- 19	-0.03	1.00
21- 20	0.20	1.00

Hospital 6

Year	T-Value	P-Value
19- 18	2.16	0.13
20- 18	-0.84	0.84
21- 18	0.59	0.94
20-19	-3.32	0.01
21- 19	-1.63	0.36
21- 20	1.53	0.42

A.26 Tukey Simultaneous Test for Difference in Scan Length Means for Chest Abdomen Pelvis Protocols with Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	0.10	1.00
20- 18	-20.40	0.00
21- 18	1.96	0.20
20-19	-21.38	0.00
21- 19	1.94	0.21
21- 20	23.46	0.00

Hospital 2

Year	T-Value	P-Value
19- 18	-0.78	0.86
20- 18	-34.23	0.00
21- 18	2.65	0.04
20-19	-34.15	0.00
21- 19	3.45	0.00
21- 20	35.46	0.00

Hospital 3

Year	T-Value	P-Value
19- 18	-0.71	0.89
20- 18	-23.65	0.00
21- 18	0.14	1.00
20-19	-22.72	0.00
21- 19	0.83	0.84
21- 20	22.76	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	-1.87	0.24
20- 18	-25.01	0.00
21- 18	-0.31	0.99
20-19	-24.27	0.00
21- 19	1.58	0.39
21- 20	25.12	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	-1.98	0.20
20- 18	-45.74	0.00
21- 18	-4.55	0.00
20-19	-41.71	0.00
21- 19	-2.51	0.06
21- 20	38.02	0.00

Hospital 6

Year	T-Value	P-Value
19- 18	4.25	0.00
20- 18	-28.65	0.00
21- 18	3.26	0.01
20-19	-35.14	0.00
21- 19	-1.00	0.75
21- 20	33.62	0.00

A.27 Tukey Simultaneous Test for Difference in Effective Dose Means for Chest Abdomen Pelvis Protocols with Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.15	1.00
20- 18	-5.66	0.00
21- 18	0.35	0.99
20-19	-5.74	0.00
21- 19	0.52	0.95
21- 20	6.30	0.00

Hospital 2

Year	T-Value	P-Value
19- 18	-0.84	0.84
20- 18	-13.37	0.00
21- 18	1.87	0.24
20-19	-12.79	0.00
21- 19	2.71	0.03
21- 20	14.71	0.00

Hospital 3

Year	T-Value	P-Value
19- 18	-0.41	0.98
20- 18	-11.00	0.00
21- 18	-1.57	0.40
20-19	-10.49	0.00
21- 19	-1.17	0.65
21- 20	8.86	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	-2.91	0.02
20- 18	-0.43	0.97
21- 18	9.30	0.00
20-19	2.84	0.02
21- 19	12.67	0.00
21- 20	10.90	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	1.15	0.66
20- 18	-15.01	0.00
21- 18	0.73	0.88
20-19	-15.51	0.00
21- 19	-0.37	0.98
21- 20	14.74	0.00

Hospital 6

Year	T-Value	P-Value
19- 18	2.47	0.07
20- 18	-8.71	0.00
21- 18	1.07	0.71
20-19	-12.00	0.00
21- 19	-1.44	0.47
21- 20	10.31	0.00

A.28 Tukey Simultaneous Test for Difference in CTDIvol Means for Chest Protocols without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-1.15	0.66
20- 18	1.19	0.63
21- 18	1.23	0.61
20-19	2.30	0.10
21- 19	2.21	0.12
21- 20	0.18	1.00

Hospital 2

Year	T-Value	P-Value
19- 18	1.40	0.50
20- 18	1.87	0.24
21- 18	2.59	0.05
20-19	0.52	0.96
21- 19	1.28	0.58
21- 20	0.75	0.88

Hospital 3

Year	T-Value	P-Value
19- 18	0.83	0.84
20- 18	0.71	0.89
21- 18	-1.35	0.53
20-19	-0.11	1.00
21- 19	-2.12	0.15
21- 20	-1.98	0.19

Hospital 4

Year	T-Value	P-Value
19- 18	-0.62	0.93
20- 18	5.45	0.00
21- 18	5.84	0.00
20-19	6.07	0.00
21- 19	6.42	0.00
21- 20	0.68	0.91

Hospital 5

Year	T-Value	P-Value
19- 18	1.93	0.22
20- 18	0.72	0.89
21- 18	0.10	1.00
20-19	-1.01	0.74
21- 19	-1.47	0.46
21- 20	-0.51	0.96

Hospital 6

Year	T-Value	P-Value
19- 18	0.02	1.00
20- 18	0.03	1.00
21- 18	-0.14	1.00
20-19	0.01	1.00
21- 19	-0.15	1.00
21- 20	-0.16	1.00

A.29 Tukey Simultaneous Test for Difference in Scan Length Means for Chest Protocols without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.83	0.84
20- 18	-0.32	0.99
21- 18	-0.66	0.91
20-19	0.48	0.96
21- 19	0.04	1.00
21- 20	-0.37	0.98

Hospital 2

Year	T-Value	P-Value
19- 18	-0.15	1.00
20- 18	-0.18	1.00
21- 18	-0.21	1.00
20-19	-0.04	1.00
21- 19	-0.07	1.00
21- 20	-0.03	1.00

Hospital 3

Year	T-Value	P-Value
19- 18	-0.18	1.00
20- 18	3.64	0.00
21- 18	0.53	0.95
20-19	3.89	0.00
21- 19	0.70	0.90
21- 20	-2.76	0.03

Hospital 4

Year	T-Value	P-Value
19- 18	-3.33	0.01
20- 18	-0.13	1.00
21- 18	-1.40	0.50
20-19	3.20	0.01
21- 19	1.75	0.30
21- 20	-1.27	0.58

Hospital 5

Year	T-Value	P-Value
19- 18	1.29	0.57
20- 18	1.29	0.57
21- 18	1.12	0.68
20-19	0.11	1.00
21- 19	0.06	1.00
21- 20	-0.04	1.00

Hospital 6

Year	T-Value	P-Value
19- 18	1.57	0.39
20- 18	-1.76	0.30
21- 18	0.65	0.92
20-19	-3.28	0.01
21- 19	-0.75	0.88
21- 20	2.20	0.12

A.30 Tukey Simultaneous Test for Difference in Effective Dose Means for Chest Protocols without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.83	0.84
20- 18	-0.32	0.99
21- 18	-0.66	0.91
20-19	0.48	0.96
21- 19	0.04	1.00
21- 20	-0.37	0.98

Hospital 2

Year	T-Value	P-Value
19- 18	1.46	0.47
20- 18	-0.01	1.00
21- 18	1.86	0.25
20-19	-1.33	0.54
21- 19	0.53	0.95
21- 20	1.73	0.31

Hospital 3

Year	T-Value	P-Value
19- 18	-0.54	0.95
20- 18	-0.06	1.00
21- 18	-2.62	0.04
20-19	0.48	0.96
21- 19	-2.17	0.13
21- 20	-2.55	0.05

Hospital 4

Year	T-Value	P-Value
19- 18	-2.24	0.11
20- 18	3.76	0.00
21- 18	5.60	0.00
20-19	6.00	0.00
21- 19	7.71	0.00
21- 20	2.04	0.17

Hospital 5

Year	T-Value	P-Value
19- 18	2.77	0.03
20- 18	-0.64	0.92
21- 18	0.14	1.00
20-19	-3.13	0.01
21- 19	-2.11	0.15
21- 20	0.67	0.91

Hospital 6

Year	T-Value	P-Value
19- 18	0.34	0.99
20- 18	-1.17	0.65
21- 18	0.63	0.92
20-19	-1.49	0.44
21- 19	0.33	0.99
21- 20	1.66	0.35

A.31 Tukey Simultaneous Test for Difference in CTDIvol Means for Chest Protocols with Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	0.34	0.99
20- 18	-0.58	0.94
21- 18	-0.23	1.00
20-19	-0.98	0.76
21- 19	-0.60	0.93
21- 20	0.36	0.98

Hospital 2

Year	T-Value	P-Value
19- 18	0.23	1.00
20- 18	-1.27	0.58
21- 18	0.06	1.00
20-19	-1.49	0.45
21- 19	-0.15	1.00
21- 20	1.20	0.63

Hospital 3

Year	T-Value	P-Value
19- 18	2.11	0.15
20- 18	0.92	0.80
21- 18	-0.71	0.89
20-19	-1.12	0.68
21- 19	-2.56	0.05
21- 20	-1.50	0.44

Hospital 4

Year	T-Value	P-Value
19- 18	-0.74	0.88
20- 18	6.86	0.00
21- 18	9.50	0.00
20-19	8.14	0.00
21- 19	10.84	0.00
21- 20	3.09	0.01

Hospital 5

Year	T-Value	P-Value
19- 18	0.42	0.98
20- 18	0.64	0.92
21- 18	-0.43	0.97
20-19	0.21	1.00
21- 19	-0.83	0.84
21- 20	-1.07	0.71

Hospital 6

Year	T-Value	P-Value
19- 18	0.23	1.00
20- 18	-0.59	0.94
21- 18	-0.33	0.99
20-19	-0.82	0.84
21- 19	-0.55	0.95
21- 20	0.22	1.00

A.32 Tukey Simultaneous Test for Difference in Scan Length Means for Chest Protocols with Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	0.86	0.83
20- 18	4.45	0.00
21- 18	1.72	0.32
20-19	3.86	0.00
21- 19	0.94	0.78
21- 20	-2.82	0.03

Hospital 2

Year	T-Value	P-Value
19- 18	-1.46	0.46
20- 18	2.02	0.18
21- 18	0.24	1.00
20-19	3.41	0.00
21- 19	1.55	0.41
21- 20	-1.59	0.39

Hospital 3

Year	T-Value	P-Value
19- 18	0.07	1.00
20- 18	2.85	0.02
21- 18	1.57	0.39
20-19	2.74	0.03
21- 19	1.49	0.44
21- 20	-0.99	0.76

Hospital 4

Year	T-Value	P-Value
19- 18	-1.14	0.67
20- 18	1.81	0.27
21- 18	0.82	0.84
20-19	3.12	0.01
21- 19	1.97	0.20
21- 20	-0.91	0.80

Hospital 5

Year	T-Value	P-Value
19- 18	-1.57	0.40
20- 18	1.00	0.75
21- 18	-1.03	0.73
20-19	2.56	0.05
21- 19	0.55	0.95
21- 20	-2.03	0.18

Hospital 6

Year	T-Value	P-Value
19- 18	1.42	0.49
20- 18	5.66	0.00
21- 18	0.52	0.96
20-19	4.31	0.00
21- 19	-0.81	0.85
21- 20	-4.79	0.00

A.33 Tukey Simultaneous Test for Difference in Effective Dose Means for Chest Protocols with Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	0.88	0.82
20- 18	0.35	0.99
21- 18	0.62	0.93
20-19	-0.57	0.94
21- 19	-0.26	0.99
21- 20	0.30	0.99

Hospital 2

Year	T-Value	P-Value
19- 18	-0.36	0.99
20- 18	-1.37	0.52
21- 18	-0.58	0.94
20-19	-1.03	0.73
21- 19	-0.26	0.99
21- 20	0.68	0.91

Hospital 3

Year	T-Value	P-Value
19- 18	1.96	0.21
20- 18	0.35	0.99
21- 18	-1.40	0.50
20-19	-1.53	0.42
21- 19	-3.09	0.01
21- 20	-1.66	0.35

Hospital 4

Year	T-Value	P-Value
19- 18	-1.40	0.50
20- 18	6.69	0.00
21- 18	9.24	0.00
20-19	8.63	0.00
21- 19	11.20	0.00
21- 20	2.99	0.02

Hospital 5

Year	T-Value	P-Value
19- 18	-0.60	0.93
20- 18	-0.44	0.97
21- 18	-1.08	0.70
20-19	0.18	1.00
21- 19	-0.46	0.97
21- 20	-0.66	0.91

Hospital 6

Year	T-Value	P-Value
19- 18	0.45	0.97
20- 18	-1.11	0.68
21- 18	-1.00	0.75
20-19	-1.58	0.39
21- 19	-1.43	0.48
21- 20	0.04	1.00

A.34 Tukey Simultaneous Test for Difference in CTDIvol Means for Lumbar Spine Protocols for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-3.49	0.00
20- 18	-0.13	1.00
21- 18	-1.13	0.67
20-19	3.28	0.01
21- 19	1.93	0.22
21- 20	-1.00	0.75

Hospital 2

Year	T-Value	P-Value
19- 18	1.62	0.37
20- 18	2.44	0.07
21- 18	2.18	0.13
20-19	0.87	0.82
21- 19	0.63	0.92
21- 20	-0.22	1.00

Hospital 3

Year	T-Value	P-Value
19- 18	0.01	1.00
20- 18	-0.46	0.97
21- 18	-0.63	0.92
20-19	-0.49	0.96
21- 19	-0.67	0.91
21- 20	-0.18	1.00

Hospital 4

Year	T-Value	P-Value
19- 18	-0.26	0.99
20- 18	9.48	0.00
21- 18	9.77	0.00
20-19	11.26	0.00
21- 19	11.48	0.00
21- 20	0.65	0.92

Hospital 5

Year	T-Value	P-Value
19- 18	-0.52	0.95
20- 18	-7.89	0.00
21- 18	-8.54	0.00
20-19	-7.49	0.00
21- 19	-8.16	0.00
21- 20	-1.12	0.68

Hospital 6

Year	T-Value	P-Value
19- 18	4.96	0.00
20- 18	5.35	0.00
21- 18	4.04	0.00
20-19	0.42	0.97
21- 19	-0.79	0.86
21- 20	-1.19	0.63

A.35 Tukey Simultaneous Test for Difference in Scan Length Means for Lumbar Spine Protocols for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.96	0.77
20- 18	4.11	0.00
21- 18	0.42	0.98
20-19	5.13	0.00
21- 19	1.28	0.58
21- 20	-3.25	0.01

Hospital 2

Year	T-Value	P-Value
19- 18	1.33	0.55
20- 18	3.45	0.00
21- 18	2.63	0.04
20-19	2.15	0.14
21- 19	1.35	0.53
21- 20	-0.75	0.88

Hospital 3

Year	T-Value	P-Value
19- 18	-2.29	0.10
20- 18	0.94	0.78
21- 18	-0.93	0.79
20-19	3.20	0.01
21- 19	1.18	0.64
21- 20	-1.79	0.28

Hospital 4

Year	T-Value	P-Value
19- 18	-1.03	0.73
20- 18	1.24	0.60
21- 18	-1.73	0.31
20-19	2.63	0.04
21- 19	-0.83	0.84
21- 20	-3.36	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	-1.72	0.32
20- 18	0.46	0.97
21- 18	-0.11	1.00
20-19	1.95	0.21
21- 19	1.27	0.59
21- 20	-0.48	0.96

Hospital 6

Year	T-Value	P-Value
19- 18	-1.37	0.52
20- 18	2.07	0.16
21- 18	1.33	0.55
20-19	3.65	0.00
21- 19	2.80	0.03
21- 20	-0.71	0.89

A.36 Tukey Simultaneous Test for Difference in Effective Dose Means for Lumbar Spine Protocols for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-4.09	0.00
20- 18	-0.05	1.00
21- 18	-1.00	0.75
20-19	3.94	0.00
21- 19	2.59	0.05
21- 20	-0.93	0.79

Hospital 2

Year	T-Value	P-Value
19- 18	2.18	0.13
20- 18	3.01	0.01
21- 18	3.21	0.01
20-19	0.90	0.81
21- 19	1.12	0.68
21- 20	0.23	1.00

Hospital 3

Year	T-Value	P-Value
19- 18	-0.50	0.96
20- 18	-0.82	0.84
21- 18	-0.83	0.84
20-19	-0.37	0.98
21- 19	-0.39	0.98
21- 20	-0.03	1.00

Hospital 4

Year	T-Value	P-Value
19- 18	0.09	1.00
20- 18	9.22	0.00
21- 18	9.04	0.00
20-19	10.56	0.00
21- 19	10.25	0.00
21- 20	0.09	1.00

Hospital 5

Year	T-Value	P-Value
19- 18	-1.22	0.61
20- 18	-8.36	0.00
21- 18	-8.01	0.00
20-19	-7.36	0.00
21- 19	-7.07	0.00
21- 20	-0.25	1.00

Hospital 6

Year	T-Value	P-Value
19- 18	3.55	0.00
20- 18	4.62	0.00
21- 18	4.09	0.00
20-19	1.15	0.66
21- 19	0.70	0.90
21- 20	-0.41	0.98

A.37 Tukey Simultaneous Test for Difference in CTDIvol Means for Pulmonary Angiogram Protocols for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.38	0.98
20- 18	3.07	0.01
21- 18	-0.47	0.97
20-19	3.34	0.01
21- 19	-0.08	1.00
21- 20	-3.48	0.00

Hospital 2

Year	T-Value	P-Value
19- 18	0.29	0.99
20- 18	6.00	0.00
21- 18	0.30	0.99
20-19	6.06	0.00
21- 19	0.03	1.00
21- 20	-5.41	0.00

Hospital 3

Year	T-Value	P-Value
19- 18	-0.87	0.82
20- 18	-3.15	0.01
21- 18	-1.40	0.50
20-19	-2.26	0.11
21- 19	-0.56	0.95
21- 20	1.63	0.36

Hospital 4

Year	T-Value	P-Value
19- 18	0.22	1.00
20- 18	11.96	0.00
21- 18	2.56	0.05
20-19	12.69	0.00
21- 19	2.50	0.06
21- 20	-8.95	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	-0.11	1.00
20- 18	-2.22	0.12
21- 18	2.04	0.18
20-19	-1.38	0.51
21- 19	1.63	0.36
21- 20	3.51	0.00

Hospital 6

Year	T-Value	P-Value
19- 18	0.74	0.88
20- 18	6.42	0.00
21- 18	0.31	0.99
20-19	5.74	0.00
21- 19	-0.41	0.98
21- 20	-5.93	0.00

A.38 Tukey Simultaneous Test for Difference in Scan Length Means for Pulmonary Angiogram Protocols for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-1.08	0.70
20- 18	-6.31	0.00
21- 18	-0.04	1.00
20-19	-4.79	0.00
21- 19	1.01	0.74
21- 20	6.04	0.00

Hospital 2

Year	T-Value	P-Value
19- 18	-2.53	0.06
20- 18	-7.95	0.00
21- 18	-0.89	0.81
20-19	-5.68	0.00
21- 19	1.49	0.44
21- 20	6.64	0.00

Hospital 3

Year	T-Value	P-Value
19- 18	-0.04	1.00
20- 18	-8.03	0.00
21- 18	0.14	1.00
20-19	-8.02	0.00
21- 19	0.18	1.00
21- 20	8.00	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	-1.56	0.40
20- 18	-13.96	0.00
21- 18	0.53	0.95
20-19	-13.31	0.00
21- 19	2.11	0.15
21- 20	14.45	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	1.58	0.40
20- 18	-4.00	0.00
21- 18	1.97	0.20
20-19	-4.15	0.00
21- 19	0.17	1.00
21- 20	4.73	0.00

Hospital 6

Year	T-Value	P-Value
19- 18	1.39	0.51
20- 18	-12.29	0.00
21- 18	1.43	0.48
20-19	-14.08	0.00
21- 19	0.09	1.00
21- 20	13.57	0.00

A.39 Tukey Simultaneous Test for Difference in Effective Dose Means for Pulmonary Angiogram Protocols for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-1.78	0.29
20- 18	-5.46	0.00
21- 18	-1.02	0.74
20-19	-3.22	0.01
21- 19	0.75	0.88
21- 20	4.14	0.00

Hospital 2

Year	T-Value	P-Value
19- 18	-1.26	0.59
20- 18	-7.03	0.00
21- 18	0.03	1.00
20-19	-6.10	0.00
21- 19	1.24	0.60
21- 20	6.76	0.00

Hospital 3

Year	T-Value	P-Value
19- 18	-0.50	0.96
20- 18	-7.07	0.00
21- 18	-0.94	0.79
20-19	-6.58	0.00
21- 19	-0.45	0.97
21- 20	5.95	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	0.02	1.00
20- 18	2.34	0.09
21- 18	14.36	0.00
20-19	2.51	0.06
21- 19	15.22	0.00
21- 20	13.96	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	0.45	0.97
20- 18	-4.53	0.00
21- 18	2.71	0.04
20-19	-3.46	0.00
21- 19	1.67	0.34
21- 20	5.81	0.00

Hospital 6

Year	T-Value	P-Value
19- 18	2.80	0.03
20- 18	-5.79	0.00
21- 18	2.01	0.18
20-19	-9.00	0.00
21- 19	-0.70	0.90
21- 20	7.86	0.00

A.40 Tukey Simultaneous Test for Difference in CTDIvol Means for Renal Colic Protocols for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	1.12	0.68
20- 18	1.08	0.70
21- 18	0.30	0.99
20-19	0.03	1.00
21- 19	-0.76	0.87
21- 20	-0.74	0.88

Hospital 2

Year	T-Value	P-Value
19- 18	0.16	1.00
20- 18	0.77	0.87
21- 18	0.84	0.84
20-19	0.66	0.91
21- 19	0.74	0.88
21- 20	0.13	1.00

Hospital 3

Year	T-Value	P-Value
19- 18	-0.02	1.00
20- 18	-0.09	1.00
21- 18	1.23	0.61
20-19	-0.08	1.00
21- 19	1.38	0.51
21- 20	1.39	0.51

Hospital 4

Year	T-Value	P-Value
19- 18	1.03	0.73
20- 18	6.67	0.00
21- 18	0.24	1.00
20-19	6.40	0.00
21- 19	0.16	1.00
21- 20	-0.37	0.98

Hospital 5

Year	T-Value	P-Value
19- 18	1.07	0.71
20- 18	0.47	0.97
21- 18	2.20	0.12
20-19	-0.49	0.96
21- 19	1.29	0.57
21- 20	1.60	0.38

Hospital 6

Year	T-Value	P-Value
19- 18	1.71	0.32
20- 18	1.78	0.28
21- 18	0.77	0.87
20-19	0.20	1.00
21- 19	-0.89	0.81
21- 20	-1.02	0.74

A.41 Tukey Simultaneous Test for Difference in Scan Length Means for Renal Colic Protocols for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.96	0.77
20- 18	1.38	0.51
21- 18	0.46	0.97
20-19	2.39	0.08
21- 19	1.40	0.50
21- 20	-0.88	0.82

Hospital 2

Year	T-Value	P-Value
19- 18	-0.43	0.97
20- 18	0.27	0.99
21- 18	0.51	0.96
20-19	0.72	0.89
21- 19	0.95	0.78
21- 20	0.27	0.99

Hospital 3

Year	T-Value	P-Value
19- 18	-0.27	0.99
20- 18	-0.50	0.96
21- 18	-0.41	0.98
20-19	-0.27	0.99
21- 19	-0.18	1.00
21- 20	0.08	1.00

Hospital 4

Year	T-Value	P-Value
19- 18	-0.14	1.00
20- 18	-1.72	0.31
21- 18	0.32	0.99
20-19	-1.78	0.28
21- 19	0.33	0.99
21- 20	0.48	0.96

Hospital 5

Year	T-Value	P-Value
19- 18	-0.32	0.99
20- 18	-0.40	0.98
21- 18	0.19	1.00
20-19	-0.12	1.00
21- 19	0.48	0.96
21- 20	0.54	0.95

Hospital 6

Year	T-Value	P-Value
19- 18	3.73	0.00
20- 18	1.69	0.33
21- 18	3.06	0.01
20-19	-2.06	0.17
21- 19	-0.40	0.98
21- 20	1.49	0.44

A.42 Tukey Simultaneous Test for Difference in Effective Dose Means for Renal Colic Protocols for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	0.60	0.93
20- 18	0.92	0.79
21- 18	0.10	1.00
20-19	0.37	0.98
21- 19	-0.48	0.96
21- 20	-0.79	0.86

Hospital 2

Year	T-Value	P-Value
19- 18	0.33	0.99
20- 18	0.37	0.98
21- 18	0.52	0.96
20-19	0.07	1.00
21- 19	0.24	1.00
21- 20	0.17	1.00

Hospital 3

Year	T-Value	P-Value
19- 18	0.04	1.00
20- 18	-0.34	0.99
21- 18	0.91	0.80
20-19	-0.42	0.97
21- 19	0.96	0.77
21- 20	1.30	0.57

Hospital 4

Year	T-Value	P-Value
19- 18	1.07	0.71
20- 18	7.18	0.00
21- 18	0.40	0.98
20-19	6.92	0.00
21- 19	0.31	0.99
21- 20	-0.26	0.99

Hospital 5

Year	T-Value	P-Value
19- 18	0.75	0.88
20- 18	0.37	0.98
21- 18	1.73	0.31
20-19	-0.31	0.99
21- 19	1.09	0.69
21- 20	1.26	0.59

Hospital 6

Year	T-Value	P-Value
19- 18	2.34	0.09
20- 18	2.22	0.12
21- 18	1.32	0.55
20-19	0.02	1.00
21- 19	-0.93	0.79
21- 20	-0.89	0.81

A.43 Tukey Simultaneous Test for Difference in CTDIvol Means for Routine Head Protocols without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	2.10	0.15
20- 18	-2.36	0.09
21- 18	-0.11	1.00
20-19	-4.50	0.00
21- 19	-2.08	0.16
21- 20	2.12	0.15

Hospital 2

Year	T-Value	P-Value
19- 18	0.37	0.98
20- 18	-2.49	0.06
21- 18	0.04	1.00
20-19	-2.93	0.02
21- 19	-0.30	0.99
21- 20	2.32	0.09

Hospital 3

Year	T-Value	P-Value
19- 18	0.06	1.00
20- 18	8.70	0.00
21- 18	0.45	0.97
20-19	8.85	0.00
21- 19	0.40	0.98
21- 20	-7.65	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	-1.85	0.25
20- 18	-0.93	0.79
21- 18	0.67	0.91
20-19	0.94	0.79
21- 19	2.50	0.06
21- 20	1.59	0.38

Hospital 5

Year	T-Value	P-Value
19- 18	3.38	0.00
20- 18	2.81	0.03
21- 18	1.51	0.43
20-19	-0.24	1.00
21- 19	-1.46	0.46
21- 20	-1.14	0.67

Hospital 6

Year	T-Value	P-Value
19- 18	16.55	0.00
20- 18	14.69	0.00
21- 18	11.43	0.00
20-19	-1.47	0.45
21- 19	-4.02	0.00
21- 20	-2.56	0.05

A.44 Tukey Simultaneous Test for Difference in Scan Length Means for Routine Head Protocols without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.05	1.00
20- 18	6.25	0.00
21- 18	-0.49	0.96
20-19	6.42	0.00
21- 19	-0.45	0.97
21- 20	-6.38	0.00

Hospital 2

Year	T-Value	P-Value
19- 18	0.22	1.00
20- 18	5.51	0.00
21- 18	0.68	0.91
20-19	5.45	0.00
21- 19	0.49	0.96
21- 20	-4.39	0.00

Hospital 3

Year	T-Value	P-Value
19- 18	0.48	0.96
20- 18	-0.70	0.90
21- 18	0.89	0.81
20-19	-1.22	0.61
21- 19	0.46	0.97
21- 20	1.58	0.39

Hospital 4

Year	T-Value	P-Value
19- 18	0.38	0.98
20- 18	8.38	0.00
21- 18	0.61	0.93
20-19	8.33	0.00
21- 19	0.26	0.99
21- 20	-7.57	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	-11.19	0.00
20- 18	-4.96	0.00
21- 18	-5.59	0.00
20-19	5.01	0.00
21- 19	4.25	0.00
21- 20	-0.63	0.92

Hospital 6

Year	T-Value	P-Value
19- 18	-0.10	1.00
20- 18	3.63	0.00
21- 18	1.57	0.40
20-19	3.61	0.00
21- 19	1.61	0.37
21- 20	-1.82	0.26

A.45 Tukey Simultaneous Test for Difference in Effective Dose Means for Routine Head Protocols without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	0.41	0.98
20- 18	-1.08	0.70
21- 18	0.46	0.97
20-19	-1.52	0.43
21- 19	0.08	1.00
21- 20	1.48	0.45

Hospital 2

Year	T-Value	P-Value
19- 18	0.43	0.97
20- 18	-3.03	0.01
21- 18	0.45	0.97
20-19	-3.54	0.00
21- 19	0.07	1.00
21- 20	3.23	0.01

Hospital 3

Year	T-Value	P-Value
19- 18	1.33	0.55
20- 18	-13.39	0.00
21- 18	5.78	0.00
20-19	-15.12	0.00
21- 19	4.65	0.00
21- 20	18.52	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	-0.47	0.97
20- 18	-2.66	0.04
21- 18	2.19	0.13
20-19	-2.29	0.10
21- 19	2.73	0.03
21- 20	4.85	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	-12.23	0.00
20- 18	-11.87	0.00
21- 18	-5.49	0.00
20-19	-0.77	0.87
21- 19	5.25	0.00
21- 20	5.57	0.00

Hospital 6

Year	T-Value	P-Value
19- 18	-1.15	0.66
20- 18	-2.37	0.08
21- 18	1.54	0.41
20-19	-1.19	0.63
21- 19	2.55	0.05
21- 20	3.65	0.00

A.46 Tukey Simultaneous Test for Difference in CTDIvol Means for Routine Head Protocols with Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.12	1.00
20- 18	-2.89	0.02
21- 18	-0.39	0.98
20-19	-2.74	0.03
21- 19	-0.28	0.99
21- 20	2.07	0.16

Hospital 2

Year	T-Value	P-Value
19- 18	1.45	0.47
20- 18	1.27	0.58
21- 18	1.91	0.22
20-19	-0.26	0.99
21- 19	0.33	0.99
21- 20	0.63	0.92

Hospital 3

Year	T-Value	P-Value
19- 18	0.25	1.00
20- 18	6.38	0.00
21- 18	0.06	1.00
20-19	6.27	0.00
21- 19	-0.16	1.00
21- 20	-5.65	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	-0.55	0.95
20- 18	-1.78	0.29
21- 18	-0.46	0.97
20-19	-1.33	0.55
21- 19	0.01	1.00
21- 20	1.17	0.65

Hospital 5

Year	T-Value	P-Value
19- 18	2.60	0.05
20- 18	1.86	0.24
21- 18	2.61	0.04
20-19	-0.72	0.89
21- 19	0.00	1.00
21- 20	0.73	0.89

Hospital 6

Year	T-Value	P-Value
19- 18	14.90	0.00
20- 18	13.31	0.00
21- 18	9.70	0.00
20-19	-1.05	0.72
21- 19	-3.43	0.00
21- 20	-2.40	0.08

A.47 Tukey Simultaneous Test for Difference in Scan Length Means for Routine Head Protocols with Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.21	1.00
20- 18	4.03	0.00
21- 18	-0.06	1.00
20-19	4.17	0.00
21- 19	0.11	1.00
21- 20	-3.45	0.00

Hospital 2

Year	T-Value	P-Value
19- 18	-1.16	0.65
20- 18	2.56	0.05
21- 18	-1.13	0.67
20-19	3.78	0.00
21- 19	0.14	1.00
21- 20	-4.05	0.00

Hospital 3

Year	T-Value	P-Value
19- 18	0.00	1.00
20- 18	-2.38	0.08
21- 18	0.62	0.93
20-19	-2.43	0.07
21- 19	0.62	0.92
21- 20	2.74	0.03

Hospital 4

Year	T-Value	P-Value
19- 18	0.26	0.99
20- 18	2.06	0.17
21- 18	2.51	0.06
20-19	1.90	0.23
21- 19	2.36	0.08
21- 20	0.55	0.95

Hospital 5

Year	T-Value	P-Value
19- 18	-5.69	0.00
20- 18	-0.24	1.00
21- 18	-5.93	0.00
20-19	5.27	0.00
21- 19	-0.21	1.00
21- 20	-5.50	0.00

Hospital 6

Year	T-Value	P-Value
19- 18	0.14	1.00
20- 18	0.01	1.00
21- 18	1.10	0.69
20-19	-0.12	1.00
21- 19	0.95	0.78
21- 20	1.05	0.72

A.48 Tukey Simultaneous Test for Difference in Effective Dose Means for Routine Head Protocols with Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.60	0.93
20- 18	-1.01	0.75
21- 18	-0.73	0.89
20-19	-0.43	0.97
21- 19	-0.22	1.00
21- 20	0.15	1.00

Hospital 2

Year	T-Value	P-Value
19- 18	-1.72	0.32
20- 18	-1.49	0.45
21- 18	-0.95	0.78
20-19	0.33	0.99
21- 19	0.93	0.79
21- 20	0.63	0.92

Hospital 3

Year	T-Value	P-Value
19- 18	-0.02	1.00
20- 18	-10.57	0.00
21- 18	3.23	0.01
20-19	-10.77	0.00
21- 19	3.30	0.01
21- 20	12.65	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	-0.37	0.98
20- 18	-0.94	0.78
21- 18	3.03	0.01
20-19	-0.62	0.93
21- 19	3.47	0.00
21- 20	3.80	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	-6.26	0.00
20- 18	-6.57	0.00
21- 18	-6.57	0.00
20-19	-0.27	0.99
21- 19	-0.27	0.99
21- 20	-0.01	1.00

Hospital 6

Year	T-Value	P-Value
19- 18	0.57	0.94
20- 18	-0.56	0.94
21- 18	1.88	0.24
20-19	-1.08	0.70
21- 19	1.34	0.54
21- 20	2.28	0.10

A.49 Tukey Simultaneous Test for Difference in CTDIvol Means for Routine Head Protocols with/without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	1.71	0.32
20- 18	1.12	0.68
21- 18	-0.57	0.94
20-19	-0.82	0.84
21- 19	-2.62	0.04
21- 20	-2.06	0.17

Hospital 2

Year	T-Value	P-Value
19- 18	1.40	0.50
20- 18	-1.19	0.64
21- 18	1.22	0.61
20-19	-2.58	0.05
21- 19	-0.09	1.00
21- 20	2.33	0.09

Hospital 3

Year	T-Value	P-Value
19- 18	-0.07	1.00
20- 18	2.86	0.02
21- 18	-0.19	1.00
20-19	3.14	0.01
21- 19	-0.13	1.00
21- 20	-3.73	0.00

Hospital 4

Year	T-Value	P-Value
19- 18	-0.19	1.00
20- 18	0.36	0.98
21- 18	-0.33	0.99
20-19	0.61	0.93
21- 19	-0.16	1.00
21- 20	-0.76	0.87

Hospital 5

Year	T-Value	P-Value
19- 18	0.41	0.98
20- 18	1.16	0.65
21- 18	1.04	0.73
20-19	0.75	0.88
21- 19	0.67	0.91
21- 20	0.00	1.00

Hospital 6

Year	T-Value	P-Value
19- 18	16.16	0.00
20- 18	16.57	0.00
21- 18	14.06	0.00
20-19	-0.35	0.99
21- 19	-2.60	0.05
21- 20	-2.36	0.09

A.50 Tukey Simultaneous Test for Difference Scan Length Means for Routine Head Protocols with/without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.84	0.84
20- 18	-5.90	0.00
21- 18	-3.93	0.00
20-19	-5.46	0.00
21- 19	-3.30	0.01
21- 20	2.31	0.10

Hospital 2

Year	T-Value	P-Value
19- 18	0.47	0.97
20- 18	-14.71	0.00
21- 18	-3.93	0.00
20-19	-15.21	0.00
21- 19	-4.39	0.00
21- 20	9.93	0.00

Hospital 3

Year	T-Value	P-Value
19- 18	-0.08	1.00
20- 18	-4.80	0.00
21- 18	-7.05	0.00
20-19	-5.08	0.00
21- 19	-7.84	0.00
21- 20	-1.02	0.74

Hospital 4

Year	T-Value	P-Value
19- 18	0.02	1.00
20- 18	-4.66	0.00
21- 18	-4.20	0.00
20-19	-5.20	0.00
21- 19	-4.66	0.00
21- 20	0.32	0.99

Hospital 5

Year	T-Value	P-Value
19- 18	-3.00	0.02
20- 18	-2.72	0.03
21- 18	-2.62	0.04
20-19	0.30	0.99
21- 19	0.09	1.00
21- 20	-0.18	1.00

Hospital 6

Year	T-Value	P-Value
19- 18	-2.82	0.03
20- 18	-5.52	0.00
21- 18	-4.92	0.00
20-19	-2.48	0.06
21- 19	-1.94	0.21
21- 20	0.54	0.95

A.51 Tukey Simultaneous Test for Difference Effective Dose Means for Routine Head Protocols with/without Contrast for Test Preformed in 2018- 2021

Hospital 1

Year	T-Value	P-Value
19- 18	-0.62	0.92
20- 18	-6.38	0.00
21- 18	-4.12	0.00
20-19	-6.24	0.00
21- 19	-3.77	0.00
21- 20	2.65	0.04

Hospital 2

Year	T-Value	P-Value
19- 18	1.09	0.70
20- 18	-19.90	0.00
21- 18	-4.18	0.00
20-19	-21.03	0.00
21- 19	-5.21	0.00
21- 20	14.58	0.00

Hospital 3

Year	T-Value	P-Value
19- 18	0.30	0.99
20- 18	-5.36	0.00
21- 18	-6.87	0.00
20-19	-6.05	0.00
21- 19	-8.13	0.00
21- 20	-0.15	1.00

Hospital 4

Year	T-Value	P-Value
19- 18	0.42	0.98
20- 18	-11.04	0.00
21- 18	-5.78	0.00
20-19	-12.75	0.00
21- 19	-6.83	0.00
21- 20	5.48	0.00

Hospital 5

Year	T-Value	P-Value
19- 18	-6.67	0.00
20- 18	-12.91	0.00
21- 18	-5.47	0.00
20-19	-6.22	0.00
21- 19	0.55	0.95
21- 20	6.16	0.00

Hospital 6

Year	T-Value	P-Value
19- 18	-1.96	0.20
20- 18	-12.49	0.00
21- 18	-7.89	0.00
20-19	-10.08	0.00
21- 19	-5.67	0.00
21- 20	4.52	0.00

Research Ethics Office
Suite 200, Eastern Trust Building
95 Bonaventure Avenue St.
John's, NL
A1B 2X5

March 15, 2022

Room 4M132, Medical Education Centre 300 Prince Philip Drive
St. John's, Newfoundland and Labrador CA
A1B 3V6

Dear Dr Gadag:

Researcher Portal File # 20222593
Reference # 2022.037

RE: Analysis of the occupation exposure to radiation among health care professionals involved in cardiac and vascular Interventional procedures.

Your application was reviewed by a subcommittee under the direction of the HREB and your response was reviewed by the Chair and the following decision was rendered:

X	Approval
	Approval subject to changes
	Rejection

Ethics approval is granted for one year effective March 14, 2022. This ethics approval will be reported to the board at the next scheduled HREB meeting.

This is to confirm that the HREB reviewed and approved or acknowledged the following documents (as indicated):

- Application, approved
- Research proposal, approved

- Data Custodian Variable list, approved
- Budget, approved

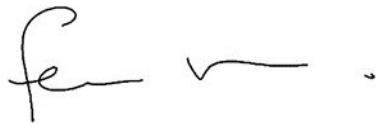
Please note the following:

- This ethics approval will lapse on March 14, 2023. It is your responsibility to ensure that the Ethics Renewal form is submitted prior to the renewal date.
- This is your ethics approval only. Organizational approval may also be required. It is your responsibility to seek the necessary organizational approvals.
- Modifications of the study are not permitted without prior approval from the HREB. Request for modification to the study must be outlined on the relevant Event Form available on the Researcher Portal website.
- Though this research has received HREB approval, you are responsible for the ethical conduct of this research.
- If you have any questions please contact info@hrea.ca or 709 777 6974.

The HREB operates according to the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2), ICH Guidance E6: Good Clinical Practice Guidelines (GCP), the Health Research Ethics Authority Act (HREA Act) and applicable laws and regulations.

We wish you every success with your study.

Sincerely,



Dr Fern Brunger, Chair Non-Clinical Trials Committee

Health Research Ethics Board