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Computed tomography working principle and its application to diagnose adult and pediatric COVID-19 patients

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***Abstract*---**Along with the increasing number of COVID-19 cases around the world, new forms of prevention, diagnosis and treatment for this disease have been widely studied globally. As the virus primarily attacks the respiratory system, computed tomography of the chest (lungs) has played an important role mainly:in the detection of pneumonia in patients with high suspicion (not yet confirmed by laboratory; in the magnitude of the evaluation of pneumonia; and in the monitoring of the respiratory condition (pneumonia) evolution in adult and pediatric patients with laboratory studies that confirm the disease. In this scenario, computed tomography (CT) has proven to be an important ally for health professionals in addition to pediatric and adult patients, since the results can help make a timely decision on the clinical direction to follow. This review paper demonstrated deeply the physical mechanism of CT machine. Moreover, in this review paper, studies have shown that in adult and pediatric patients with laboratory evidence of COVID-19, CT images showed lung lesions with very specific features. This imaging pattern had already been published in scientific journals and are now helping radiology clinics and hospitals around the world look for early signs of COVID-19 disease in symptomatic adult and pediatric patients who are still awaiting laboratory diagnostic results.

***Keywords*---**pediatric, COVID-19, computed tomography (CT).

Introduction

The development of medicine, both in the diagnosis and treatment of diseases, is the result of the evolution of diagnostic tests based on X-rays or ionizing radiation, such as conventional radiography (Bader et al., 2007), mammography (Hollada et al., 2015), computed tomography (Boice Jr, 2015), angiography (Reddy

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et al., 2010), interventional radiology (Johnson et al., 2001) and nuclear medicine (Mettler Jr et al., 2009). These tests based on ionizing radiation are the main sources of human exposure to artificial ionizing radiation. This is because, with the use of ionizing radiation, it is possible to visualize the internal and anatomical structures of the human body through images obtained during the examination, without any complex or surgical procedure. After the discovery of X-rays, scientists Allan M. Cormack and Sir Godfrey Hounsfield, created computed tomography (CT), through the use of mathematical methods in the construction and mechanical process of CT, with the aim of visualizing composite soft tissues and the brain structure (Nicholls, 2019).

Subsequently, CT was applied in medicine to perform diagnostic exams in different anatomical regions of the body and, in this way, CT exams have increased in recent years in the world (D'Angelo et al., 2019; Greess et al., 2000). In developing countries, the increase was more than 50% in the number of exams performed in the last decade (Brodersen et al., 2020; Rivera-Ortega & Molina-Molina, 2019; Shankar et al., 2019; J. Wang et al., 2020). One of the reasons for this increase is due to the ability of CT to detect and differentiate the attenuation coefficients of each biological tissue and, thus, make it possible to distinguish tissue density levels that are very close or even similar. The resolution of images and detailing of complex biological tissues, with different densities, is of high resolution in CT, unlike conventional radiography, as CT has a sensitivity of detection of different attenuation coefficients of up to 10 times greater than a conventional X-rays (Fattore et al., 2020; Gharieb, 2022; Massimi et al., 2021).

This possibility has influenced physicians to request a CT scan to study soft tissue images in regions such as the skull, chest and abdomen. In 2020, there was an increase in the amount of CT chest exams performed, due to the Pandemic caused by Covid-19. At the end of 2019, the circulation of a new Coronavirus (SARS-CoV-2) was identified, and its transmission between humans, through direct contact or contact with contaminated surfaces and objects (Goyal et al., 2020). This disease affects the lungs and respiratory system, resembling pneumonia. The CT images of the chest allow the visualization, evaluation and monitoring of the extensions of the disease, showing signs of infection of the Coronavirus, namely, ground-glass opacity, consolidations and an reversed halo sign (Caruso et al., 2020; Cozzi et al., 2021; Hu et al., 2020; Poerio et al., 2020). In this way, it is possible to follow the evolution of the clinical conditions of patients infected by Covid-19, both asymptomatic and symptomatic with severe pulmonary complications. Due to breathing difficulties, patients need respiratory equipment, and during the CT examination, they need to be accompanied by a health professional nurse/radiology technician, to perform manual ventilation of the patient, especially in children. During the chest CT examination, it is essential that the patient remains immobile or performs minimal movement, for this reason some children are sedated and placed in a manual respiratory system, in which the nurse or radiology technician manually performs breathing control, holding and releasing air from the lungs, when requested by the radiologist, to obtain images of the chest. There are other situations in which a professional needs to accompany the patient during the CT exam, such as those necessary in special care in patients with multiple traumas, child restraint or patient restraint and administration of contrasts for PET/ CT (Hull et al., 2022; Liszewski et al., 2022; Tiddens et al., 2021).

When accompanying patients with Covid-19, during the CT examination, professionals run the risk of being contaminated by the virus, in addition to the biological effects from exposure to ionizing radiation. During a CT procedure, X-rays can interact directly or indirectly with the tissues and molecules of the human body, thus causing tissue reactions or stochastic effects (Ghoneim et al., 2022; Jari et al., 2022; KARACA, 2021).

The first cases of emergence or appearance of biological effects were dermatitis, skin cancer, leukemia, cataracts and brain tumors, in healthcare professionals, radiology and in the multidisciplinary team, due to daily exposure to ionizing radiation. The emergence of these biological effects in professionals gave rise to the term "occupational exposure" (Davis, 2018). Occupational exposure is a global concern, therefore, in the literature, several studies can be found regarding the doses received by interventional radiology professionals (Adliene et al., 2020; Barnholtz-Sloan et al., 2018; Davis, 2018).

However, there are few studies on exposure of patients to CT, which study doses in professionals who accompany patients during the conventional CT examination (Ahmed et al., 2019; Costa et al., 2018; Osipov et al., 2020; Portela et al., 2021). In different CT studies of the skull, the researchers observed an equivalent dose in the practitioner's eye lens of 0.2 mSv (Nagi, 2021). With the results obtained by the dosimeters, Khamwan et al., (2010) concluded that the doses around the CT equipment were 96 µGy in front of the gantry and 0.42 µGy on the sides (Khamwan et al., 2010). In the literature, the few studies found used physical phantoms and dosimeters, which are limited tools and resources, since technological advances already allow the use of virtual anthropomorphic simulators, which are more efficient and present similarities in the real structures of organs and tissues present in the human body (Giansante et al., 2019; Lee et al., 2007; Lee et al., 2020; Long et al., 2013; Van Straten et al., 2009), making it possible to efficiently determine the absorbed doses in each organ. In this sense and considering the scenario of the Covid-19 Pandemic, this review paper aimed to study literature data on exposure of adult and pediatric emergency patients to ionizing agents in imaging tests, today and in times of COVID-19.

Covid-19 and the use of Computed Tomography

In China, in December 2019, the first cases of Severe Acute Respiratory Syndrome Corona virus 2 (SARS-Cov-2) were reported (, later named by the World Health Organization (WHO) as Covid-19 (Liu et al., 2020; S. Wang et al., 2020; Xie et al., 2020). SARS-Cov-2 is a single-molecule RNA (ribonucleic acid) virus composed of at least 30,000 nucleotides (Alexandersen et al., 2020; Tian et al., 2020; Zhao et al., 2020). Sisk & Frieman (2001) point out that this virus is part of the group of coronaviruses, causing Severe Acute Respiratory Syndrome (SARS) and Middle East (MERS-Cov), in which the genome of this new coronavirus presented 79% of the genetic sequence of the virus, causing SARS and approximately 50% of MERS (Sisk & Frieman, 2001). Patients infected with the virus that causes Covid-19 may be asymptomatic or have flu-like symptoms, such as fever, cough, fatigue (McDade et al., 2021; Pascarella et al., 2020; Swain et al., 2020).

In some cases, the clinical picture can progress to serious respiratory problems, due to the process of interstitial pneumonitis (Catania et al., 2021; Shimizu et al., 2022). In addition, Covid-19 has a high transmission range, through droplets in direct contact or contact with contaminated surfaces and objects (Choi et al., 2021; Mehraeen et al., 2021; Santarpia et al., 2020). Because of its transmission power, Covid-19 quickly spread around the world, and on March 11, 2020, the WHO National Organization decreed the state of Pandemic (Dantas et al., 2020; Sverzellati et al., 2020). This new disease caused the death of thousands of people, according to the simultaneous data of the interactive panel to track Covid-19, created by researcher Ensheng Dong and made available by the ArcGis website (Figure 1).

Figure 1: Tracking the spread of pandemic disease as designed by Ensheng Dong. (https://www.esri.com/about/newsroom/blog/how-researchers-built-johns-hopkins-dashboard/)

To May 25, 2022, more than 526 million cases have been confirmed worldwide. Jordan had 1.7 million cases, ranking forty-two among the countries with the most confirmed cases of Covid-19. Unfortunately, at the same time, more than 6.28 deaths were recorded in the world, with 14,066 deaths in Jordan, being the country with the lowest recorded deaths caused by Covid-19 in Middle East. The standard diagnostic test used to confirm the infection caused by the corona virus is based on the virus RNA polymerase reaction (RT-PCR), in which droplet samples and secretions from the nose and throat are collected. However, this test has a high rate of false negative results and is unavailable for mass population testing (Artik et al., 2022; Surkova et al., 2020; Tahamtan & Ardebili, 2020; Teymouri et al., 2021). In addition, this test does not establish the degree of lung infection that the virus causes in the patient. In the search for a diagnostic tool that provides such information, Hu et al. (2020) used the conventional CT scan in 41 patients diagnosed with Covid-19, publishing the first article with the patterns and signs of pulmonary infection caused by the Coronavirus (Hu et al., 2020).

Based on the work by Hu et al. (2020), CT images of the chest in patients with Covid-19 were used in China and around the world, with the medical objective of visualizing, evaluating and monitoring the extensions of the disease, caused by virus infection, namely, ground-glass opacities, consolidations and inverted halo sign (Bernheim et al., 2020; Hu et al., 2020; Shu et al., 2020). These standard signals obtained on CT images help in the diagnosis of asymptomatic patients, or with false negative RT-PCR. In this way, it is possible to diagnose and monitor the evolution of the clinical conditions of patients infected by Covid19. However, it is important to point out that CT images cannot be the only exam for confirming Covid-19, and the RT-PCR exam is necessary, so that the doctor can determine the patient's contamination by the virus (Gietema et al., 2020; Hao & Li, 2020; Khatami et al., 2020).

The study by Steinberger et al. (2020), conducted with 30 pediatric patients aged 1 year to 14 years of both sexes, determined standard signs of infections of the Covid-19 agent virus on chest CT images in these patients, from the early stage to the of 21 recovery (Steinberger et al., 2020).

Brief History of Computed Tomography

In 1895, a milestone in the history of the scientific community and the medical field occurred, with the discovery of X-rays by the physicist Wilhelm Conrad Röntgen. This discovery made it possible for the first time to visualize internal anatomical parts of the human body, without the need for surgical interventions (Bull, 1980; Hurlock et al., 2009; Uldin, 2017). Subsequently, there was the development of diagnostic tests based on X-rays, or on ionizing radiation, such as conventional radiography, mammography, computed tomography, angiography, interventional radiology, nuclear medicine, among others. In the available literature on the discovery of Computed Tomography (CT), one can find two leading scientists, Allan M. Cormack and Sir Godfrey Hounsfield, who influenced and created this diagnostic tool. When dealing with the physicist Cormack, his contribution was in the creation of the mathematical method to determine coefficients of doses absorbed by the human body, in different anatomical regions, but especially those made up of soft tissue, in 1963. The engineer Hounsfield, on the other hand, focused on the formulation, construction and mechanical process of CT, with the aim of visualizing composite soft tissues in the brain structure, and thus he was considered the inventor of CT (Cierniak, 2011; Hsieh & SPIE, 2009; Zenger & GmbH, 2015).

The prototype created by Hounsfield used slices (parts) of brains from animals, such as pigs and cattle, to obtain images using ionizing radiation, produced by the X-ray tube. Hounsfield's objective was to obtain images of a three-dimensional object (3D) through slices (axial) in order to show parts of soft tissue present in the brain (Carmignato et al., 2017). Following previous studies, Hounsfield found that it was more efficient to image slices of the brain than to consider the entire brain (volume) during the radiation process, but the duration for collecting information was around 9 days, and another 2, 5 hours to rebuild the image on the ICL 1905 mainframe (Carmignato et al., 2017).

According to Hounsfield himself, he presented the results obtained with the brain of animals at the 32nd British Institute of Radiology Congress (Shaw, 2014). This aroused the interest of physicians and scientists to apply Hounsfield's studies in the area of human neurology, as well as companies, such as Electrical Musical Instruments (EMI) Ltd, in developing a CT scanner for humans. The first medical CT images were performed in London, in 1972, at the Atkinson Morley hospital. The images were obtained by a CT scanner from the British company EMI, with the aim of diagnosing a neural tumor located in the frontal lobe region of a 41-year-old female patient (Strong & Hurst, 1994).

As a result of their research, the success and efficiency of CT in the field of diagnostic medicine, A. M. Cormack and S. G Hounsfield won the Nobel Prize in medicine in 1979. In addition, they influenced the advances of studies in the area of neuroscience by through CT scans of the skull (Lutters & Koehler, 2021; Strong & Hurst, 1994).

From there, the great increase in the production and commercialization of tomographs in the world began. In 1972, two years after the first medical images, there were already around 60 EMI devices around the world, and in 1980, this number increased to more than 10,000 (Thomas & Banerjee, 2013). This boosted other companies, such as Siemens, to invest in the tomography production market. The differences between current tomographs and the first equipment reside in the way of obtaining images, determined by the number of detectors, the X-ray tube, the mechanical equipment, reconstruction and the exposure time to obtain the image (Thomas & Banerjee, 2013).

The entire history of tomography has been marked by the planning and creation of X-ray tube mechanisms with detectors to obtain better images in the shortest possible time. The first tomography prototype produced a pencil beam of X-radiation (pencil beam) and had a single detector, in addition, its movements were linear and semicircular day to obtain all the images of the studied region (Bashkirov et al., 2016; Boyd, 1977; Cierniak, 2011). The second mechanism was marked by the use of up to 30 detectors and the change from the pencil-type beam to a partial fan beam, resulting in a decrease in the image acquisition time to 300 seconds (Bashkirov et al., 2016; Boyd, 1977; Cierniak, 2011). In the third mechanism, the movement of the beam in a narrow fan with more than 800 detectors was highlighted, leading to an acquisition time of only 1 to 5 seconds (Bashkirov et al., 2016; Boyd, 1977; Cierniak, 2011). The fourth mechanism comprises the continuous rotational movement of the source in a fan opening and with multiple detectors fixed on the arc, taking the acquisition time to less than 1 second (Bashkirov et al., 2016; Boyd, 1977; Cierniak, 2011). The fifth mechanism is the latest CT technology, which uses two X-ray tubes and a double detector array, which provide optimal image quality in just 0.33 seconds (Bashkirov et al., 2016; Boyd, 1977; Cierniak, 2011).

CT Operation: Components and Image Acquisition

The tomography exam can be defined as a sequence of images in planes or cuts, and in this way the cuts made in the anatomical structures of the human body are not superimposed on the images obtained (DeMaio, 2017; Seeram, 2015). In a CT room, the main components of the equipment are the gantry, the patient's stretcher and the control system. Each component is essential for the examination, in which the patient is positioned on the stretcher that will be moved into the gantry (DeMaio, 2017; Seeram, 2015). In a simplified way, the examination is carried out with the movement of the stretcher and 360o rotation of the X-ray tube and the set of detectors. The movement mechanism of the X-ray tube and the table varies according to the image acquisition configurations, being axial, helical or multi-slice. Each of these configurations represents a generation of CT scanners and the technological advance applied in medicine to improve the performance and quality of images. The first image acquisition configuration was axial (conventional) in which each slice was obtained by a turn of the X-ray tube and detector set. For the next slice, the radiation from the tube is interrupted and the table is repositioned, and so on until the acquisition of the full image of the anatomical region. Unlike axial acquisition, the helical (volumetric) configuration is characterized by the simultaneous movement of the table with the rotation of the X-ray tube and detectors to obtain the images. Helical acquisition enabled the growth in the use of CT for studies of the thorax and abdomen, due to the advantage of obtaining images in a time interval similar to the duration of a breath, reducing the appearance of artifacts in the images (DeMaio, 2017; Seeram, 2015).

Using the same mechanism of simultaneous movement of the table and the X-ray tube, the acquisition of multislices differs from the helical in relation to the number of slices performed, since the acquisition of the image of the anatomical region is obtained by multiple slices. Due to the set of detectors present in the tomograph, multiple cuts are performed in one rotation of the X-ray source (DeMaio, 2017; Seeram, 2015). With multi-slice acquisition, there is less patient exposure to radiation and better image quality (DeMaio, 2017; Seeram, 2015).

Regardless of the image acquisition configuration, the CT gantry is an arc support composed of 3 central or main components for performing the exam, which are the X-ray tube, set of collimators and detectors. The X-ray tube is responsible for the production of X-rays with energy between 20 and 150 keV. The CT equipment has a system of filters for low energies, as well as a system of collimators positioned before and after the patient. The pre-patient collimator has the function of delimiting the size of the opening (width) of the radiation beam, necessary to perform the specific exam in the anatomical region of study, without increasing the dose received by the patient. Generally, this collimator varies the beam thickness from 0.5 to 20 mm (Seeram, 2015), according to the irradiated region. That is, the pre-patient collimator defines the slice thickness. To reduce the scattered radiation, the post-patient collimator is used (Seeram, 2015). This collimator sets image quality standards and removes much of the scattered radiation.

Generally, the detectors of a tomography are of gases or solids (scintillators), according to the model, in which the sensitivity efficiency in detecting photons is approximately 27, 70% for solid detectors and 90% for gas detectors (Seeram, 2015). The radiation or the energy of the photons deposited in the detectors are converted into numbers of a scale, or level, of radiation attenuation (Seeram, 2015). The information received at the detectors are transformed into digital signals by the image reconstruction system. The historical evolution of the tomograph presented two detector arc configurations, with one row (Single Detector Computed Tomography) or more rows (Multi Detector Computed Tomography). The number of cuts performed during a complete tube rotation (360°) is proportional to the number of rows in the detector arc. In other words, in CT scanners with multiple detectors, more cuts are performed in a complete rotation of the X-ray tube. This arc (array) of detectors influences the acquisition of data, the construction and the quality of the images.

The array of detectors is important for the acquisition of images obtained through collimation and attenuation of ionizing radiation. For this acquisition of images, the CT scanners have a fundamental spatial resolution system that makes it possible to distinguish very close tissue density levels. In this way, the different compounds, or biological substances, are delimited by an attenuation coefficient scale represented by the number of TC, which has the Hounsfield unit (HU) (Sandborg, 1995; Seeram, 2010). This attenuation coefficient scale is represented by bands or levels from -1000 (air) to +1000 (bones) HU, based on level 0 (water).
With the UH attenuation coefficient scale, each biological tissue has a value converted into gray, white (upper +1000) and black (lower -1000) variations on the CT image. This is because each CT number is the result of the interaction of ionizing radiation with tissue of a certain density. Thus, the highest attenuation coefficients are represented in the image by lighter tones. The lowest attenuation levels are the darkest tones (Durick, 2001; Hyatt, 2009; Jung, 2021; Liguori et al., 2015).

This system of changing the viewing windows, and the ability to detect and differentiate the attenuation coefficients in each biological tissue, influences the choice of physicians to request the CT exam for the study of images of soft tissues of organs in anatomical regions, such as the skull, thorax and abdomen, instead of the conventional radiography of X-ray. According to Chen et al., (2013), Ji et al., (2019) and Taguchi, (2017), CT has a sensitivity of detection of different attenuation coefficients of 10 times greater than a conventional X-ray exam (Chen et al., 2013; Ji et al., 2019; Taguchi, 2017). Because of this sensitivity of CT, its use was intensified during the Covid-19 pandemic, as the images obtained help in the diagnosis of the disease and monitoring of the extensions of lung inflammation caused by the Coronavirus (Katal et al., 2020; Rorat et al., 2021; Yang et al., 2020).

Interactions of Ionizing Radiation with Matter

By using ionizing radiation, the images of diagnostic tests are the result of the interaction of radiation with different materials and biological tissues (Seeram, 2015). Seeram (2015) explain that the interaction of radiation with the medium occurs when there is a change in the energy or direction of the photon. That is, when a beam of radiation strikes a material, an interaction occurs, in which a good part of the energy is absorbed, and the other part passes through this material, having a new beam of emerging radiation that has an intensity different from the initial energy of the photon, before the interaction (Seeram, 2015).

This process is called photon attenuation, which varies exponentially according to the thickness of the material in which the radiation interaction occurs, according to the Lambert-Beer law (Schmitt & Niggemann, 2011; Seeram, 2010). In this way, the greater the thickness of the irradiated body, the lower the intensity of the emerging beam, as there will be attenuation of the beam by the material.

It is because of the radiation attenuation process with biological tissues that CT images are obtained, as presented in many studies (Schmitt & Niggemann, 2011; Seeram, 2010). In addition, there are also two predominant effects of interaction of radiation with matter, in this range of energies, which are the photoelectric and Compton effect. The prevalence of effects is related to the energy of incident radiation and the atomic number of the target material. In this way, it can be observed that for photons with low energies, interacting with a medium with a higher atomic number, the photoelectric effect prevails. Considering the characteristics of CT scans, the Compton effect is predominant (Schmitt & Niggemann, 2011; Seeram, 2010).

Photoelectric effect

In 1905, the physicist Albert Einstein explained the photoelectric effect (EINSTEIN, 1905), which consists of an interaction and complete transfer of the energy of a photon with the electron present in the atom. Low-energy photons, produced in the X-ray tube, interact with an electron in the atom. If this energy is sufficient or greater than the electronic binding energy, this electron absorbs all the energy and will be ejected from the electronic cloud with a certain kinetic energy. This kinetic energy of the ejected electron is obtained by the difference of the incident photon energies and the electronic binding energy (OKUNO, 2010; BUSHBERG, 2012; TAUHATA, 2013). In addition, with the imbalance in the electron cloud of the atom, in which the ejected electron creates a vacancy, another electron, of a higher energy level, moves to this lower level.

Compton effect

Unlike the photoelectric effect, in which all the energy from the photon is transferred to the electron, in the Compton effect only part of the energy is absorbed by the electron present in the atom. In his studies on the effects of X-rays on graphite, the physicist Arthur H. Compton explained that this effect comes from the conservation of energy and momentum during the interaction of the photon with the electron (Daniel et al., 2013; Roessl & Proksa, 2007; Schmitt & Niggemann, 2011; Seeram, 2010; Steadman et al., 2011; Toyokawa et al., 2008). Thus, during a CT scan, a photon with high energy, produced in the X-ray tube, strikes an electron present in the atom, to which it transfers part of its energy. The deflected photon ends up influencing the increase in doses to the patient and the multidisciplinary team present in the room. The Compton effect is also responsible for reducing image quality.

Biological Effects from Ionizing Radiation

In a diagnostic procedure such as CT, X-rays can interact directly or indirectly with molecules in the human body, and thus cause biological effects. It is noted that the photon interacts directly with the DNA molecule and thus causes ionization and a direct change in the composition of that cell. In indirect interaction, photons interact with water molecules present in the body and create free radicals during the hydrolysis process (Armao & Smith, 2014; Brody et al., 2007; Frush & Applegate, 2004; Huda, 2007; White & Mallya, 2012). These, in turn, can damage the cell's DNA.

These interactions of radiation with biological tissues can cause physical and chemical effects on human cells. Each effect varies according to the type of radiation, time of onset of effects of radiation exposure, and the amount of dose (Amundson et al., 2001; Barendsen et al., 1963; Dainiak, 2002; Marchetti et al., 2006; Nikitaki et al., 2016). For example, epilation occurs for doses greater than 3 Gy, erythema for 6Gy and desquamation for 15 Gy ((i Garau et al., 2011; Ounsakul et al., 2016). On the other hand, stochastic effects do not have a dose threshold for their appearance. The severity of these effects does not depend on the amount of dose received by the body. Generally, stochastic effects appear late after radiological exposure, in which cells undergo a process of cellular alteration or mutation, resulting in neoplasms (Burgio et al., 2018; Casey et al., 2015; Dalcı et al., 2006; Robertson et al., 2013; Scott et al., 2003). Much of the data and information about these biological effects caused by exposure to radiation come from studies carried out with people who were exposed to radioactive elements, such as, for example, survivors of accidents or nuclear attacks, and patients and the multidisciplinary team exposed to ionizing radiation during examinations (Baker, 2016; Sherer et al., 2013).

Radiosensitivity: Child and Adult

The number of doses received and the biological effects caused by the interaction of radiation vary according to the age of the patient, for example, when an adult and a child are submitted to the same CT examination, with the same parameters and factors for obtaining the images. The effects on children are more harmful than on adults. This is because the radiosensitivity of children is approximately 3 times greater than that of adults, influencing the increase in the probability of tissue reactions or stochastic effects (Almohiy, 2014; Brody et al., 2007; de Jong, Lindblad, et al., 2006; Ogbole, 2010; Shah & Platt, 2008; Stein et al., 2009). It is worth mentioning that each patient has a different immune system and functioning of the body, which directly interferes with the issue of whether or not neoplasms arise (Amini et al., 2013; Brody et al., 2007). Also, another factor that influences the probability of cancer occurrence, for example, in children, is life expectancy (de Jong, Mayo, et al., 2006; Pauwels & Bourguignon, 2012). Children are expected to have more years to live than an adult. According to Stein et al. (2016), the child is in the phase of cell development and multiplication, in addition to having a longer life expectancy than the adult to develop certain disease (Stein et al., 2016). Each cancer has a latency period to develop in the person's body, for example, considering that a given cancer has a latency period of 25 years and two patients exposed to ionizing radiation, an adult of 60 years and a pediatric of 6 years (Brody et al., 2007; Nievelstein et al., 2010; Stein et al., 2016). The greatest probability of occurrence of this risk will be in children, as it is expected that they will have a life expectancy greater than the adult of 60 years, after exposure to ionizing radiation. In their studies with adults of different age groups, Suit et al. (2007) determined that a 50-year-old patient is one-third as likely to experience cancer as a result of radiological exposure, compared to a 30-year-old patient (Suit et al., 2007).

A study created a graph based on data from estimates by the International Commission on Radiological Protection (Report 60) to illustrate the Oncogenic Potential and the probability of cancer mortality varying according to the exposure dose as a function of the age of the patient exposed to high doses of radiation (Brenner et al., 2001).

Also, studies demonstrate estimates of the probability of the occurrence of a fatal cancer in pediatric patients, throughout life, after exposure to ionizing radiation in low-dose diagnostic tests. When performing exams in the abdominal region, Sun et al. (2010) estimated the probability of having a cancer at 1 in 550 one-year-old children (Sun et al., 2010). As for the skull, the probability is 1 in 1500 children submitted to the exam (Sun et al., 2010).

Studies, in the United States of America, determined that annually 600,000 diagnostic tests using ionizing radiation of the anatomical regions of the abdomen, thorax and skull are performed in children, and the estimate is that approximately 500 children will develop a fatal cancer (radioinduced) (Brenner et al., 2001). According to another study, the doses received in children during the CT procedure are approximately 30 mGy and 50 mGy, which would triple the probability of leukemia and brain tumors, respectively (Pearce et al., 2012).

The diagnosis of SARS-CoV-2 infection begins with clinical suspicion and epidemiology. The child has a typical mild viral condition: cough, runny nose, headache and fever and does not progress with severity. Gastrointestinal symptoms such as diarrhea and skin manifestations such as rash are uncommon, but are more common in the pediatric population (Zimmermann & Curtis, 2020). Confirmatory diagnosis is made by detecting viral genetic material in airway secretions. Serology plays an important role in the absence of a confirmatory test, as it indicates the host's immune response against the virus, signaling previous infection (Zimmermann & Curtis, 2020).

Imaging tests are responsible for evaluating pulmonary involvement and are not very specific. Chest radiography in some cases shows no changes. Chest CT is more sensitive and may show ground-glass opacity, condensation, septal thickening, and mixed opacities. However, when indicated, the level of radiation must be suitable for children. Therefore, children infected with SARS-CoV-2 have a mild clinical picture (Bayramoglu et al., 2021). Confirmatory diagnosis is made by detecting the virus in respiratory secretions and serology demonstrates the immune response. Chest radiography is not very sensitive and chest tomography (CT) helps in monitoring lung injury (Serrano et al., 2020). Confirmatory diagnosis is made by detecting the virus in respiratory secretions and serology demonstrates the immune response.

Occupational exposure in CT

The first cases of biological effects in radiology professionals and in the multidisciplinary team, due to daily exposure to ionizing radiation, were dermatitis and skin cancer, leukemia, cataracts and brain tumors (Leuraud et al., 2015; Linet et al., 2010; Linet et al., 2012; Roguin et al., 2013). The emergence of these biological effects in professionals gave rise to the term "occupational exposure" (McRobbie, 2012; Shafiee et al., 2016; Stam & Yamaguchi-Sekino, 2017). In interventional radiology, there are many works related to occupational exposure (McRobbie, 2012; Shafiee et al., 2016; Stam & Yamaguchi-Sekino, 2017). In CT, there are few studies, which study doses in professionals who accompany patients during the conventional CT examination, in the administration of contrasts on PET/CT and on CT image-guided fluoroscopy (Beyer et al., 2004; Palm & Frida, 2017; Townsend et al., 2004; von Schulthess et al., 2006). European study aimed to identify the knowledge of 56 professionals (doctors and nurses) about radiation protection and the biological effects caused by ionizing radiation during CT examination and created a system called "traffic light", which establishes different areas of exposure to ionizing radiation in a CT room, where professionals can stay or not, according to the dose level (Heilmaier et al., 2016). The experimental studies by Palmand and Frida (2017) with dosimeters and physical phantoms of the chest aimed to determine the radiation doses spread in a CT room during the chest examination of an adult and thus carry out safety observations and radiological protection of professionals. in hospitals in Vietnam (Palm & Frida, 2017).

With dosimeters distributed around the room and around the CT equipment, one study determined that the dose was 96 μGy in front of the CT gantry and 0.42 μGy on the sides (Saha, 2012). In their recent study, Liebmann et al., (2014) and Sookpeng et al., (2019) verified the influence of patient positioning (centering), during the CT examination of the skull, on the doses received in the eyes of professionals who accompany this patient close to the gantry (Liebmann et al., 2014; Sookpeng et al., 2019). Both studies concluded that the positioning of the patient, in the isocenter and outside it, influences the significant increase of doses in the eyes of professionals, with a variation of 0.1 to 0.2 mSv, depending on the position of the professional and the patient.

Radiological Protection

Due to the biological effects caused by exposure to ionizing radiation and the misuse of this type of radiation, it was necessary to create an international commission on radiological protection - International Commission on Radiological Protection (ICRP), which creates and promotes norms regarding the use and application of ionizing radiation, determines dose limits, and develops guidelines for the care and radiological protection of patients, employees and the community in general (Cousins et al., 2011).

Since 1928, ICRP has been studying and evaluating better ways to manage the radiation doses emitted by the equipment and doses received by patients and professionals, in carrying out diagnostic tests to obtain images (Cousins et al., 2011). With ICRP guidelines, each country defines its radiological protection commission, its principles and basic means of dose management and control (Cousins et al., 2011). Three principles were established that are fundamental for radiation protection, namely:

1. Justification: Exposing an individual to ionizing radiation without justification is prohibited. In this way, the performance of radiological exams and procedures must be requested by a professional (Physician) and this request must be justified according to the patient's needs. In the case of requesting a CT scan of the chest for patients with Covid-19, there is justification, as the images help in the diagnosis, assessment and monitoring of the progress of the disease. In general, exams that use ionizing radiation are of paramount importance for the diagnosis or treatment of the patient, and thus the benefits of the exams outweigh the harm of exposure to ionizing radiation (Cousins et al., 2011).
2. Optimization: As the radiological examination is necessary and justified, the optimization of equipment, protocols and procedures should be prioritized, so that the lowest radiation doses are the minimum radiation used in the examination, and thus achieve the objectives, without changing the quality of the images. That is, the optimization is intertwined with the national ministries of health. In this way, the tomographs have an Automatic Exposure Control (Automatic Exposure Control), which, according to the anatomical region and the patient's weight, changes the main physical and mechanical parameters of the tomograph automatically. Thus, this system "creates" protocols for each patient, in order to minimize (optimize) the amount of radiation to be received by the patient when performing the exam. "Care Dose 4D system (Siemens)" is common example (Cousins et al., 2011; GUERRA et al., 2021).
3. Limitation: A limit value of the dose received by the multiprofessional team exposed to ionizing radiation directly or indirectly is stipulated, so that it does not exceed the determined threshold. According to Radiation Detection Company RDC 330 (2021), the professional's annual effective dose cannot exceed 20 mSv. If the stipulated limit is reached, the professional must be removed from activities and investigate the reasons that led to doses close to or above the stipulated limit (Cousins et al., 2011; GUERRA et al., 2021).

In situations where the professional needs to monitor and perform special care in patients with Covid-19, with multiple traumas, and the containment of the patient, especially children, in computer tomography exams, it is essential to follow these principles of radiological protection. RDC 330 (2021) determines that professionals must use radiological protection equipment (PPE) during the radiological examination, with the apron, glasses and thyroid protector composed of the element lead. However, several studies pointed out that interventional radiology professionals do not use PPE or use them incorrectly, and these actions are also performed by CT professionals (Cousins et al., 2011; Darafsheh et al., 2020; GUERRA et al., 2021; Guha-Sapir et al., 2020; Leshner, 2020; Michel-Kabamba et al., 2020).

Dosimetric examination

Scientists and researchers concerned with optimizing the doses received by patients and professionals during a diagnostic exam or in an interventional radiology procedure, carry out dosimetric research aimed at the quality of exams and minimization of exposure to ionizing radiation. Among these studies (Assié et al., 2005; Mettivier et al., 2022; Newhauser et al., 2007; Zaidi & Xu, 2007), Monte

Carlo simulation which created in the 1940s, in the development of the Manhattan Project, was used as a mathematical and statistical tool. The purpose of the Monte Carlo tool is to statistically calculate the interactions of radiation with matter, through the energy transport of different particles, such as photons or neutrons, commonly used in nuclear physics (Boswell et al., 2011; Dementyev & Sobolevsky, 1999; Wan Chan Tseung et al., 2015).

In the literature, Monte Carlo is used in different areas of medical physics, such as in the simulation of radiological examinations, interventional radiology procedures and nuclear medicine, to statistically estimate the values of doses received in the organs and tissues of professionals and patients (Chan et al., 1985; Gialousis et al., 2008; Tapiovaara et al., 1997). With the evolution of computer systems, different Monte Carlo codes can be found, such as PENELOPE and MCNPX (Daures et al., 2011; Uusijärvi et al., 2009; Vilches et al., 2007; Ye et al., 2004).

Together with the Monte Carlo code, virtual anthropomorphic phantoms are integrated with the aim of simulating the anatomical structures of the human body, according to the shapes, densities and compositions of different types of biological tissues, such as lung tissue, adipose tissue , soft and bony (Li et al., 2011; Ljungberg et al., 2002; Ramos et al., 2017; Zaidi & Tsui, 2009; Zaidi & Xu, 2007).

Like Monte Carlo codes, virtual anthropomorphic simulators have also undergone a process of evolution over time due to technological advances. The first simulators were the mathematical ones, which were composed of structures and geometric shapes, such as planes, squares, circles and ellipses (Greggio et al., 2008; Leidner et al., 2016). The MIRD (Medical Internal Radiation Dose) Committee was the primary mathematical simulator of dosimetric studies with virtual phantoms, in addition to ADAM (male model) and EVA (female model), the last two being created by Latin American scientists (Bolch et al., 2009; e Silva et al.; Fill et al., 2004; Kramer et al., 2004; Loureiro et al., 2004; Toohey et al., 2000; Yamaguchi, 1978).

Also, mathematical simulation objects were created to represent children of different age groups (Bolch et al., 2009; Han et al., 2006; Smith et al., 2000). By means of CT and magnetic resonance images, phantoms based on voxels were created, with the following examples being, VOXELMAN, NORMAN and NAOMI, representing males and females, respectively (Xu, 2014; Zaidi & Tsui, 2009; Zaidi & Xu, 2007; Zradziński, 2015).

Currently, there are new virtual anthropomorphic phantoms with adaptation and improvement of voxels objects, in which the anatomical structures of the phantoms present more real similarities of the structures of organs and tissues present in the human body, through mesh surface. There are also hybrid phantoms, which use mathematical geometries more smoothly, with polynomial meshes, surface curves and three-dimensional dimensions (Glick & Ikejimba, 2018; Khodajou-Chokami & Dylov, 2019; Petoussi-Henss et al., 2014). The mesh computational phantoms are, for example, RPI-AM and RPI-AF, FASH and MASH, which are representations of female and male adults (Cassola et al., 2009; Cassola et al., 2011; Kramer et al., 2009; Yeom et al., 2014).

Dosimetric Quantities

To carry out the management and study of doses, it is necessary to know and define some dosimetric quantities, being absorbed dose, equivalent and air kerma (BAHREYNI et al., 2006; Hobeila & Seuntjens, 2002; Kellerer et al., 1992; Shiragai et al., 1982). Each magnitude represents a meaning in the interpretation of doses, and especially in the analysis of the risks of biological effects and in the determination of dose limits, guaranteeing radiological protection. The absorbed dose ($\boldsymbol{DT}$) is characterized by being a physical quantity, which represents the amount of energy absorbed by the mass of tissue or matter after the interaction of radiation (Mattsson & Söderberg, 2013; Sgouros, 2005). The absorbed dose varies according to the type of radiation, which can be obtained through the average energy (dE) divided by the mass of tissue with which the interaction occurred (dm), according to equation 1. (Carlsson, 1981).

$$D_T = \frac{dE}{dm} \text{.......}(1)$$

The unit of absorbed dose corresponds to the ratio of energy and mass units (J/kg), having the dosimetric unit Gray (Gy) (Broerse & Barendsen, 1986; Carlsson, 1981; Sabol et al., 2014). Depending on the type of radiation and on which material or tissue the interaction will take place, the biological effects may be different. In this way, to determine the absorbed dose, the weighting factor ($\boldsymbol{w_R}$) is used, according to the type of radiation. According to Brix (2014), the weighting factor of photons and electrons, for all energies, corresponds to the value 1. On the other hand, for high particles, the weighting factor is 20, and neutrons vary from 1 to 20, according to the energy (Brix et al., 2014). With these weighting factors, it is possible to calculate the equivalent dose ($\boldsymbol{H_T}$), through the product of the absorbed dose (D_T) and the radiation weighting factor (w_R), according to equation 2 (Brix et al., 2014).

$$H_T = D_T . W_R \text{ ....}(2)$$

As it is a protection quantity, the equivalent dose unit is in Sievert (Sv). Also, the effective dose ($\boldsymbol{E}$) is a protective quantity, used to analyze the whole-body dose received after the interaction of ionizing radiation (Brix et al., 2014). Each tissue is composed of different chemical elements, and in this way they can manifest different reactions or effects, according to the radiosensitivity of each tissue. In this way, each tissue has a tissue weighting factor ($\boldsymbol{wT}$).
Once the tissue weighting factors are established, the effective dose (E) can be calculated, which is the sum of the equivalent doses (H_T) multiplied by the tissue weighting factor (w_T), according to equation 3.

$$E = \sum_T \quad H_T . W_T \text{....}(3)$$

With the calculation of the effective dose, the value of the estimated dose to the whole body is obtained, where the unit is Sievert (Sv).

The Kerma quantity (K) is a physical quantity that represents the ratio of the sum of the initial kinetic energies (dE_c) of each particle released by photons, incident on a material of material or tissue mass (dm) (Cousins et al., 2011). Generally, this kerma is obtained at the output of the X-ray equipment, according to equation 4

$$K = \frac{dE_c}{dm} \ldots .(4)$$

But when it comes to CT dosimetry, the calculation of the air kerma magnitude differs from conventional radiology. Where the air kerma ($\boldsymbol{Ca},\mathbf{00}$) on tomography can be obtained by the pencil-like ionization chamber. Air kerma is calculated by taking the integral of the kerma (K) along the axis of rotation of approximately 100 mm in length, and considering the number of slices (N) and the thickness (T) of them in obtaining the images, following equation 5 (Cousins et al., 2011).

$$C_{\alpha,100} = \frac{1}{NT}\int \quad K(z)dz \ldots\ldots(5)$$

This air kerma has the unit of Gray (Gy) and it is not necessary to have a phantom object to obtain its value from the pencil chamber. There are other physical quantities TC, but they will not be addressed in this work, as we will only use air kerma to determine the conversion coefficients (CC). The Conversion Coefficient (CC) is used to normalize the equivalent dose (H_t) received by air kerma ($C_{\alpha,100}$□□), in which quantities obtained in a computational way can be related to Monte Carlo and virtual phantoms , or experimentally following equation 6.

$$CC[H_T] = \frac{H_t}{C_{\alpha,100}} \ldots\ldots(6)$$

In this work, using the Monte Carlo code, the Conversion Coefficient for Equivalent Dose ($\boldsymbol{CC}[\boldsymbol{H_T}]$) with the photon weighting factor (which is 1), and for all organs except bone marrow, through the tally equation 6 command (in MeV/g/particle). The effective dose conversion coefficient ($C[E]$) is obtained by adding the tissue weighting factors (Wt) multiplied by the conversion coefficients of the equivalent doses of all tissues (Ht) for males and females, divided by 2, according to the equation 7.

$$CC[E] = \sum_t \quad W_t \frac{CC[H_t]^{male} + CC[H_t]^{female}}{2} \ldots\ldots(7)$$

This conversion coefficient for effective dose is important for analysis and management of doses and radiological protection of professionals and patients. In this way, this work will present the values of $C[H_t]$and $CC[E]$ obtained from professionals who perform manual ventilation in pediatric patients, during the computed tomography examination in the chest region.

Conclusion

In this manuscript, we showed that CT is a valid tool in the diagnosis of Covid-19 — as long as it is related to clinical and laboratory data. Its indication cannot be trivial, but rather judicious and carried out with caution. The correct use of tomographic findings in the conclusions of the reports depends on the expertise of the medical team in the treatment of each patient. Thus, a clinic specializing in diagnostic imaging should be chosen.

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