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# Evolution of computed tomography techniques

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**ABSTRACT**

Recently, computed tomography (CT) scanners, which combine X-rays and computers, have been developed and adopted globally as diagnostic tools. We found it necessary to chronicle the development of CT technology and identify the factors of their widespread application and the sequence of introduction and adoption of installed optical equipment, including the events that caused the advancement of these technologies and their impact on medical services. The twentieth century was full of scientific events and a wealth of information available to scientists and innovators worldwide, challenging the restrictions imposed on the space for technology transfer and the sharing of science and information that may limit coverage. Developments in emerging inventions and innovations. Through this paper, we review the main CT techniques developed. This work focuses on hardware and systematic evolution following the timeline associated with innovations that have contributed to image reconstruction technology.

***Keywords:*** A computerized tomography scan, CT -Tomography, image reconstruction, processing, imaging by sections.

## 1. Motivation

In 1895, W.C. Röntgen discovered X-rays, which was a real revolution in medical diagnosis due to their ability to give a view from inside the body. Because of its limitations represented in physical properties, scientists focused on studying two-dimensional projections of bones. They found it difficult to diagnose tumors and soft shadow tissue and the inability to determine locations behind solid bones (Shao et al., 2020). This is what prompted researchers to invent "computed tomography" and try to create images of specific cross-sections or "slices" of the body by sending X-rays from multiple angles of the patient (Sosa et al., 2022). Due to the risks of exposure to large doses of radiation and the inability of CT X-rays to distinguish between soft tissues or differentiate between tumors and normal tissues (Müssig et al., 2020), physicist Alan Cormack proposed a theoretical method for tomography in 1963 (Carbonell Carrera & Bermejo Asensio, 2017). Cormack performed calculations to measure X-rays after they passed through the body, determined radiation absorption values, and derived the mathematical formulas necessary to build the supposed image structures in cross-sections (Turkan et al., 2017). Five years later, Godfrey Hounsfield presented a model of the device that closely resembles the theoretical specifications presented by Cormack; without knowing about Cormack's study, he experimented with using computers to display digital data patterns and improve CT X-ray images (Redondo et al., 2013; Turkan et al., 2017). Hounsfield wrote a proposal to build a scanner based on these ideas and later supervised the project to build a primitive medical experiment in 1968 that was effective and prompted him to pursue developing and refining the prototype each time (Kysela & Štorková, 2015; Redondo et al., 2013).

In 1971, he successfully built a head scanner, which was tested at Ambrose Hospital. An experimental diagnosis was performed, and an image of the tumor was successfully obtained (Dunleavy et al., 2009). Soon, head scanners spread from the UK to the US, and their effectiveness was completely confirmed.

Many teaching and research hospitals opened in the US, including Georgetown and Cleveland Clinic (Wei et al., 2015; Ye et al., 2020), so that radiologists receive technical training on devices and equipment and learn about methods of interpreting and analyzing CT images on computer screens. With the advent of 1976, factories for CT scanners and others had emerged.

Medical equipment spreads in France, Germany, Israel, Japan, Mexico, and the Netherlands (Chong et al., 2018; Ford & Minshall, 2019; Kong et al., 2016; McMenamin et al., 2014; Scalfani & Vaid, 2014). By the beginning of 1977, large scanners and CT machines could scan the entire body, were equipped with X-ray detectors, and could rotate around the body more quickly, providing greater accuracy and a faster pace (Codd & Choudhury, 2011; Gerson & Van Dam, 2003; Josman et al., 2008; Ke et al., 2020).

The development of computers, equipment, and software, along with the use of contrast agents, has gradually improved image quality and expanded the scope of radical concept (Ceccaldi et al., 2016; Modesti & Kanaar, 2001; Pinto & Flaus, 2010; Polo & Jackson, 2011). In fact, we found that contrast agents are an independent science that parallels the technical development of optical spaces, which are materials that are ingested or injected and help improve image quality. Further, the high-speed cardiac scanner was introduced in 1983 (Li & Zou, 2005).

Moreover, we note the increasing growth in computed tomography installations in member countries of the Organization for Economic Cooperation and Development, including Belgium, France, Greece, Italy, Netherlands, the US, Israel, the UK, Denmark, and Germany (Lamarche et al., 2010; Mirza-Aghazadeh-Attari et al., 2019; Shibata & Jeggo, 2020; Ström et al., 2004; Wang et al., 2002). At the same time, this field's relative decline and backwardness were clear in countries that do not enjoy such membership. In 1988, the German Siemens devices were developed, helical scanners that make a quick spiral pass along the patient's length (see **Figure 1**), a technology that differs from the traditional "slice by slice" system.

In 1992, the Israeli Elscint devices were developed. when multi-slice scanners increased scanning speeds, these devices were characterized by installing X-ray sources and detectors in rows, imaging several slices simultaneously. According to international standards, the clinical value of Elscint CT devices has decreased despite their superior performance speed due to the low quality of the image.

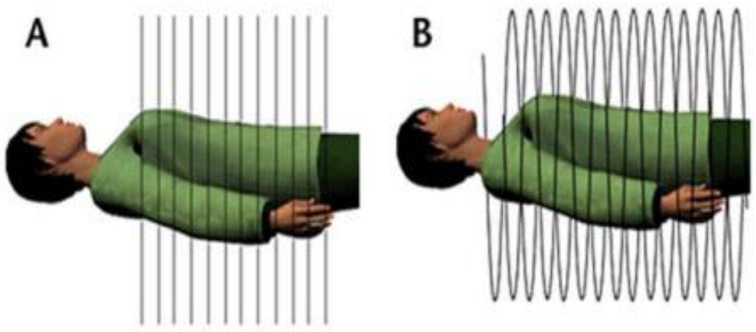


**Figure 1.** X-ray path in conventional (A) and spiral (B) CT scans.

Recently, experts have aspired to obtain cross-sectional images that combine helical and multi-slice designs (Ünal et al., 2004). Consequently, scanners have been developed that can capture image data four times faster, meaning eight times faster than the old devices.

It is characterized by reducing radiation exposure (Mognato et al., 2009) and supporting diagnostic applications. It performs accurate detection even in exceptional circumstances such as accidents and disasters, including identifying internal bleeding, scanning body and head trauma, and detecting heart and blood problems (Noda et al., 2012).

## 2. Introduction

Recently, with advances in the development of computers, the application of multi-faceted theories in physics, mathematics, chemistry, electronics, and computers aims to achieve the requirements of technology based on the ideas of computed tomography (Shao et al., 2020) and the scientific consensus on which it is based on mathematical proofs. Beginning with the success of Boheme C. in calculating the distribution ratios of radon gas in a layer of material when the values are integrated, it is found along certain lines that pass through the same layer in 1917 (Shao et al., 2020). It was viewed as essentially a practical reconstruction of the separation of matter for optical reconstruction, which prompted J. Frank, in 1938, to develop the optical back-projection technique to reconstruct X-ray images along a selective axis (Sosa et al., 2022). In 1963, Bracewell worked on creating an algorithm for image reconstruction. It has been approved for use in CT scanners (Müssig et al., 2020). Gabriel Frank obtained a brief patent for this invention in 1938, where the body was exposed to a cylindrical film to form a slice (Turkan et al., 2017), which encouraged Cormack to conduct many tests between 1957 and 1963 and to conduct his experiments and applications for this type of reconstructive tomography (Turkan et al., 2017).

He has achieved significant improvement in radiotherapy planning and developing a method for calculating radiation absorption distributions in the human body based on transmission measurements (Carbonell Carrera & Bermejo Asensio, 2017), and these applications were based on his hypothesis, recording the smallest absorption differences in soft tissue structures. With the practical implementation of G. N. Hounsfield's radon theory in 1972, computed tomography has become one of the most important tools used in the world (Müssig et al., 2020; Sosa et al., 2022). It was not easy to manufacture radiological equipment, but with Hounsfield's invention, laboratory activity shifted from manufacturing records and electronic components, including those required by CT-scanner devices (Antonelli et al., 2015; Redondo et al., 2013). In 1974, the first conventional head computed tomography (CT) device was approved. After that, many similar devices followed until 1972, when a CT scanner was installed for clinical purposes at Atkinson Morley Hospital in London, and the result of the examination performed on the first patient was the discovery of a cystic tumor in the frontal lobe (Redondo et al., 2013; Turkan et al., 2017). This was convincing evidence of the accuracy of CT scans and the effectiveness of CT scans in diagnosing tumors. This technology is considered the most important invention in diagnostic radiology. It was developed by using cylindrical lenses and rotating film technology to conform to the body while scanning, recording, and electronically controlling all components of the X-ray tube located in the

CT machine. Because of all these advantages, both Hounsfield and Cormack received Nobel prizes in medicine in recognition of their efforts in 1979. X-ray technology relies on providing a radiographic image of a three-dimensional (3D) structure; the object image is represented in 2D. However, during the filming process, dimensions and all levels are lost. Parallel X-ray films are perpendicular to each other; thus, an image is a projection of a three-dimensional volume onto a two-dimensional surface. The reason for this is the superposition of structures, which causes the high contrast to disappear. On radiographs, while it is clear in the bones, it appears in the air cavities when imaging the respiratory system. However, asymmetry may also occur in soft tissue areas like blood vessels surrounded by muscles. As for low contras, certain elements (such as iodine and barium), known as contrast media, are used and injected into the bloodstream to reduce energy levels. Through X-rays, blood vessels become visible in the image (Lee et al., 2022). Therefore, computed tomography (CT) technology is capable of evaluating poor radiographic contras. It provides in-depth information. When producing a 2D image of a 2D plane (slice), there is no overlap between structures, and the contrast of the image is improved. Furthermore, on this basis, it is a technology that can produce an image of one level in the body.

X-rays are produced when electrons are emitted from the material in the cathode tube by emission. The electron rays are accelerated and focused into high potential and collide with a target of which it is a part anode (as in **Figure 2**).

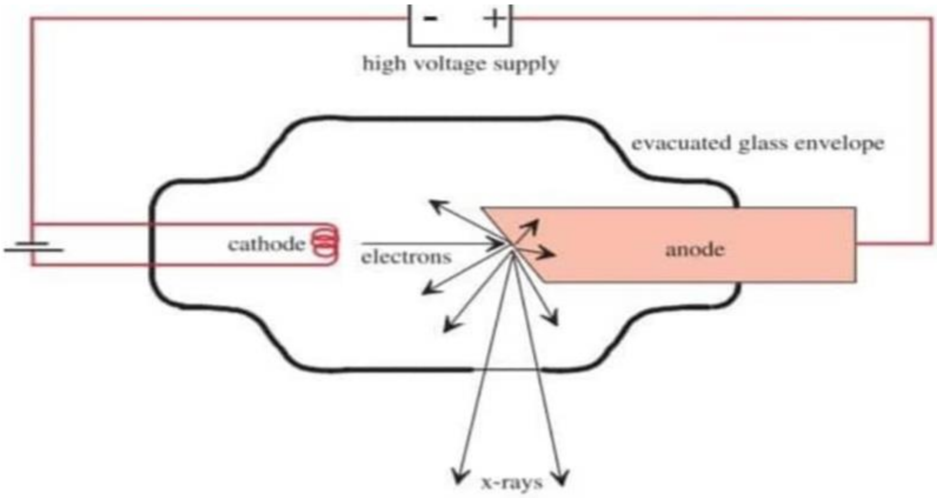


**Figure 2**. Illustration of X-ray computed tomography (Sosa et al., 2022).

**Figure 2** represents a schematic of an X-ray tube. Here, the anode is shown as fixed, and it is noted that X-rays are emitted in all directions parallel to the lead shield (not shown in the figure) to produce and collect the electron beam. X-ray emission occurs due to the sudden deceleration of the ejected electrons on the nuclei or collision of the target electrons, a process called Bremsstrahlung that produces X-rays, followed by characteristic X-rays.

The electron is slowed down by the Coulombic interaction with the electrostatic field of the target nucleus, and when

the electron slows down and loses kinetic energy, transforming into electromagnetic radiation. Finally, the result of the difference in the kinetic energy of an accelerating (or decelerating) charge; as for electromagnetic rays, the amount of this energy emitted depends on how close the emitted electron is from the target kernel. The process includes Bremsstrahlung X-rays, where energy ranges from zero to maximum. As for emitted electrons, they are numerically equal to the electrical energy used to operate the X-ray tube, accelerate the electrons, and are measured in kilovolts. It is called Bremsstrahlung, the name of white radiation because of the broad continuous spectrum of the resulting X-ray energies (Dunleavy et al., 2009; Marnef & Legube, 2017). It also grows characteristic rays of vacant shells.

It arises from throwing an electron at a target atom that is ionized by the emitted electrons. When electrons descend from the outer shells and are filled, the vacuum is released, and the excess energy emanates through X-rays. As for the characteristic X-rays, they are unilateral and dependent on the binding energies of emitted electrons and their type; the atoms in the anode emit

X-rays simultaneously. In the case of tomography, X-ray tubes operating at 100-150 keV are often used because the emitted electron does not lose all its energy in one interaction. This is because it undergoes multiple collisions with the outer electrons of the target atoms, which mainly increases temperature, increasing the belief that only a small percentage of the ejected electrons undergo X-ray production reactions.

Modern photography methods have succeeded in providing a deeper understanding of medical science, exploring different materials, and exploiting the precise information that has developed in anatomy. X-rays are waves of electromagnetic energy that behave similarly to light rays. Shorter wavelengths and the ability to penetrate thick objects are generated during the Bremsstrahlung process when the hysteresis phenomenon occurs, and the primary electron beam is forced to enter the electric field surrounding the nucleus of the atoms in the sample (Marnef & Legube, 2017; McMenamin et al., 2014; Wei et al., 2015; Ye et al., 2020). The emission of K shell electrons is essential due to high energy. X-rays are emitted when an electron is expelled from an internal orbit in the atom.

X-ray tubes are used to create X-ray photons from the electrical energy provided by X-ray generators (Scalfani & Vaid, 2014), and recently, the synchrotron has become a source for producing X-rays `by high-energy electrons orbiting around the synchrotron. Synchrotron rays can be used multiple times. There are several methods and stages of photography (Li & Zou, 2005; Mirza-Aghazadeh-Attari et al., 2019; Wang et al., 2002). In the diagnostic scope, X-rays interact through two main processes that affect the formation of the radiograph. The first is known as the photoelectric effect (photoelectric absorption), and the second is the Compton effect. Clinically, Roentgen images are two-dimensional, in addition to 3D images obtained from computed tomography (CT) machines.

Using X-rays, a technique developed by different attenuation of X-rays in structures, means the composition and density of different tissues are the reasons contrast is obtained through X-ray transmission. It is absorbed into hard tissues, such as bone structures, to a greater extent than surrounding tissues. This paper discusses protocols for applying this technique to achieve acquisition and outlines image reconstruction and restoration methods.

## 3. Methodology and discussion of previous studies

This study uses the comparative approach that relies on comparison in studying medical imaging. Computed tomography, or CT scan, is a diagnostic medical test that relies on X-rays by creating a three-dimensional image of the body's internal organs from several two-dimensional images taken around a fixed axis of rotation. It is necessary to review the methods of applying medical tests and analyses during diagnosis to control the management of treatment techniques and gain a deep understanding of the operations of image reconstruction. In 1972, Godfrey implemented the theory of work done in tomography technology. During that period, Hounsfield developed a device for measuring radiometric density by conducting many experiments based on Alan Matheson's mathematical theories and MacLeod Cormack's ideas regarding X-rays. Since 1964, and as a result of the success of Godfrey's experiment, examination of bones, blood vessels, and soft tissues has become possible inside the body.

The scanner application is based on a series of two-dimensional X-rays. For multi-angle projections, 3D images or slides are processed and created using a computer. The three-dimensional nature of CT scans affects the provision of detailed information compared to radiographs. Conventional scanners have evolved to confirm absorption contrast predictions. Therefore, it has been adopted as one of the most important methods for imaging hard tissues such as bones. Modern research and studies are working on imaging soft tissues through contrast-enhanced imaging technology and introducing phase and dark fields to measure and photograph soft tissues, such as liver tumors, brain tissue, and lung nodules. The development of X-ray CT scanning systems is based on the application of modern theories in mechanical science, electronics, and computer technology.

To improve data quality and readability, researchers are working to speed up CT scanning times and reduce the resulting images to suit clinical purposes. It is suitable for non-clinical studies and has many applications in discriminating soft and hard tissues in the head, neck, abdomen, and chest, such as liver, lung tissue, fat, and bone, and detecting types of abnormalities such as lesions, tumors and metastases within different organs, thus obtaining information about their sizes, spatial locations, and texture. Thus, it is necessary to perform a CT scan of the abdomen because it contains many organs of the digestive, urinary, endocrine, and reproductive systems, including the liver and kidneys, pancreas, spleen, digestive system, and the area surrounding these organs, to evaluate lesions, injuries or deformities and to investigate the effects of oncology treatments (Wei et al., 2015).

This procedure is often performed repeatedly to evaluate bone damage or damage to joints and diagnose lesions and fractures. CT scans also provide information about head injuries and study the causes of headaches, dizziness, strokes, and brain tumors. In this case, tests are frequently performed to detect abnormalities and diagnose shortness of breath and unexplained cough, chest pain, fever, and detection of lung nodules, which is a method common in chest CT scans, has been successful in diagnosing small nodules, and progress is made with each new generation of CT scanners.

Due to radiation risks, doctors are working to reduce the dose exposure to radiation distributed during CT scans after modifying the acquisition protocol (Dunleavy et al., 2009). Several researchers have begun to codify CT image reconstruction techniques and propose ways and means for new systems (Ke et al., 2020; Polo & Jackson, 2011). Hence, phase contrast and dark-field X-ray imaging mean the ability to enhance and analyze medical images. Many studies have also been conducted to measure network interference (Redondo et al., 2013) and conclude rates of scattering and refraction of X-rays by the scanned object, thus obtaining phase contrast and dark field. And experiment with several reconstruction and noise reduction methods to improve image quality (Ceccaldi et al., 2016; Polo & Jackson, 2011). It is necessary to note the metrological development in CT scanners, taking into account its standards to avoid deterioration of the quality of images in medical examinations, which means follow-up correction operations, periodic maintenance of devices and equipment, or removing them from service. Instructing the patient to follow safety instructions, such as neutralizing metallic materials, selecting desired positions, and carefully selecting scanner parameters is necessary.

Because they are the most vital factors, tomographic reconstructions depend on the development of computers to increase the efficiency and performance of advanced devices, assuming the attenuation object coefficients measured from a set of projections (transmission) and values, arranging data into a series of parallel beams and the projection at an angle θ, thus deepening the understanding of the inverse problem based on Beer-Lambert's law, describing absorption given by the relation:

$$\boldsymbol{I = I_0 e^{-\int \mu(x,y) ds}} \qquad \textbf{(1)}$$

The intensity is straight, where μ (x, y) indicates the attenuation coefficient specific to each object type and points to the sender. It is also noted that the analytical methods used in reconstruction are a class of image techniques such as CT scan, which is common in commercial scanners and often uses filtered back projection (FBP) and a one-dimensional projection filter. The data is before back projection (2D or 3D), covering the image space (Carbonell Carrera & Bermejo Asensio, 2017; Ford & Minshall, 2019; Shao et al., 2020). Several limitations reduce the performance of the analysis. During reconstruction for medical applications, various scenarios, such as ignoring noise associated with measurements, can be overcome by influence during post-filtering operations. As for iterative reconstruction procedures in a class of algorithms, they begin by assuming the image and then comparing them with the values measured in real-time during operation so that adjustments continue until they are reconciled. As shown in **Figure 3**, after the CT scan is acquired and the projections are measured, a first image estimate is generated, and then the X-ray beam is simulated via the frontal projection. To obtain simulated projection data, compare it with the measured projection data.

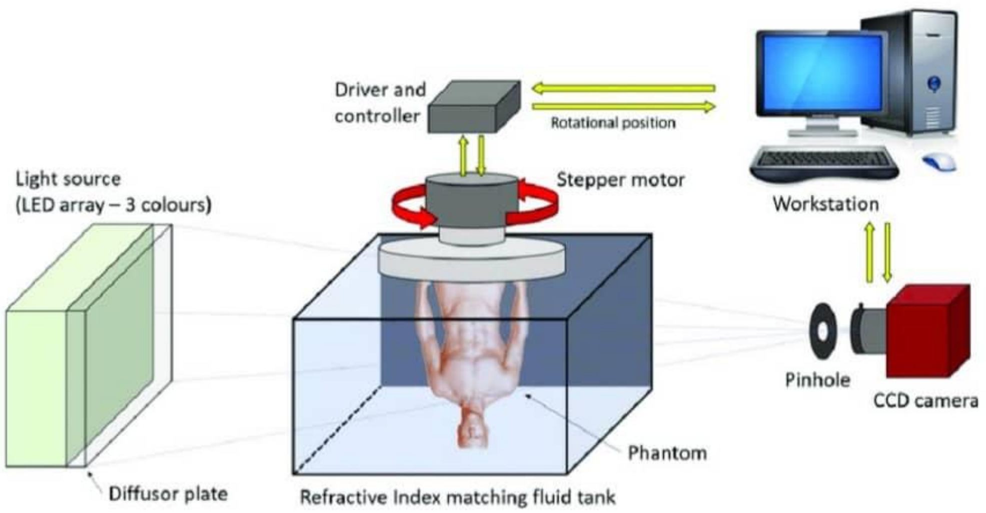


**Figure 3**. Simplified diagram of iterative reconstruction (Marnef & Legube, 2017).

If there is a difference, image estimates are updated based on spatial features, which is considered a basic procedure (Pinto & Flaus, 2010). As for the Algebraic Reconstruction Technique (ART), the more relevant iterative approach was first applied in practice by Kaczmarz in 1937 (Wei et al., 2015) and used independently by Gordon et al, a reconstruction algorithm is defined as the art of using a set of projections to rebuild a given object. Assuming the original linear problem is AX = Y, it can be written as follows:

$$\sum_{j=1}^{N} a_{ij}\, x_j = y_i, s.t. \quad i = 1,2, \dots \dots, M \;\; and \; j = 1,2, \dots \dots, N, \qquad (2)$$

Where $a_{ij}$ is the weighting parameter that indicates the effect of cell i on the integration line j, $x_j$.

It is a constant equal to j cell density value, N indicates the total number of cells, and M indicates the total number of rays (Chong et al., 2018; Codd & Choudhury, 2011; Modesti & Kanaar, 2001). In 1984, the Simultaneous Algebraic Reconstruction Technique (SART) appeared and was accompanied by major changes in the standard artistic approach and its impact on projection data Limited. It has been found that reconstruction can be performed in just one iteration, which has been shown in superior performance compared to the ART approach (Gerson & Van Dam, 2003; Ye et al., 2020). Scientists have concluded that maximum likelihood projections (MLEM) assume measurements that are not considered models for the possibility of appropriate conditions and standards for the photon to ensure a reduction in radiation doses.

Probability (PL) has become a way to look at a model's complexity while estimating the bar meters from different models, instead of MLE implementation is simple, where the log-likelihood is imperfect. The range is thus expanded depending on the model and the number of parameters (Sosa et al., 2022).

## 4. Conclusion

In conclusion, it's clear that Roentgen discovered X-rays, and Hounsfield designed the first clinical CT scanner; many approved methods for X-ray and CT imaging have been proposed. Most included more advanced detail within the confines of the survey. This ensures the continuity of imaging techniques despite the contrast between stage and dark field.

Thus, one may demonstrate that it has the ability to improve medical imaging applications. The development of computers has had a positive impact on the innovation of advanced processing methods, such as tomographic reconstruction methods. Reducing the dose also worked. Use more stringent protocols to develop radiation protection systems and thus expand the scope of CT imaging for medical scenarios. Therefore, CT has become an important technology in the examination, diagnosis, treatment, and study of many conditions, including diseases and deformities.

Finally, we note that the technology of multi-slice and helical computed tomography (CT) scanners, radiation dose adjustment techniques, and image reconstruction algorithms by iterative methods are an addition to the developments of modern scientific research and the importance of a relationship between technology, economic development, and international cooperation. Further, international organizations and institutions to support and codify research work have witnessed great development.

By reviewing previous literature and studies, it is confirmed that there are major trends, methods, and standards that establish the foundation for further development in this field.

Provided that all flows and supporting information are available, and with an insight into the relationship between technology and economics that is already happening, in development, we noticed a lack of cooperation, partnership, and equality between the currents and the absence of a comprehensive model to ensure that progress occurs at a faster rate than it is now. We find it necessary to make some recommendations with the aim of settling the concept of the relationship between technological aspects and the economy.

Due to the influence of economic and environmental conditions on the development of scientific research. We also recommend conducting more research to develop a more detailed conceptual framework that should be carefully tested. Based on our work at the Benghazi College of Medical Technology and the academic and technical program, we offer the following recommendations:

1. It is necessary to work on developing a national strategy for adopting the concepts of the knowledge economy, identifying mechanisms to support scientific research, and providing the Benghazi Medical Technology College with laboratories to ensure the implementation of this strategy.
2. Paying attention to academic and technical research and study centers in order to stimulate innovation, invention, and excellence among researchers and those interested in medical technology and medical imaging projects in a way that serves the development of medical services and supports the economic growth of the country.
3. Through this paper, we notice the advancement of science and excellence in member states of the Organization for Economic Co-operation and Development (OECD), which is an intergovernmental economic organization that includes 35 member states, founded in 1961 to stimulate economic progress and global trade. It also has a notable activity in transferring technology between member states. We recommend that you join Libya, this organization, to achieve a real partnership in medical technology programs and what will bring good and societal development to the country.
4. We recommend forming research groups and spreading team spirit among technical researchers in the medical radiology department to gain in-depth knowledge of the mechanism of forming diagnostic medical radiology images and their dependence on the nature of the energy used in radiological imaging devices. For example, some rely on the X-ray spectrum, and others depend on the use of waves. Ultrasound, magnetic field energy, and radio waves are used in MRI.

**Conflict of Interest**

On behalf of all authors, the corresponding author states that there is no conflict of interest.

**Data Availability**

No data was used for the research described in the article.

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