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Innovations of Radiology

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Abstract

Change in health care has been rapid in the last two decades with new technologies being invented every day. The radiology department has seen many of these changes. With each new technology advancement, the employees in these departments must be willing to adapt and learn how to use new equipment in order to provide patients with more efficient care. Among the changes that have developed digital imaging, portable x-rays, artificial intelligence systems, MIP/three-dimensional reconstructions, electronic ordering, surgical imaging equipment, fluoroscopy, and automatic image stitching have significantly changed the way medical imaging has flowed and improved to benefit of the patient and technologists.

Before digital imaging came along, technologists would have to run film through a developer and determine whether this film was suitable for diagnosing the patient. This was a several minute process. Today with digital imaging x-rays are available for instant review after exposure. The image is on the screen within seconds of taking the x-ray. Digital systems have automatic exposure chambers that measure the amount of radiation until a threshold is reached and then it disables the x-ray. The software is able to determine when the body part has received an adamant amount of radiation to create a quality image. This helps to control how much radiation the patient is receiving. In turn, this cuts down on potential side effects that patients can receive from too much radiation exposure. Digital images are stored with the PACS digital system, saving environmental waste. It also makes it easier to access by the patient and other health care providers. Portable radiology significantly benefits patients who are unable to transport very well. Being able to bring the machine to them provides more comfort for the patient. It also reduces strain on the technologist body if they are not having to pull on the patient to get them onto the x-ray table. Mobile imaging is also an option for patients who do not want to

leave their home. These portable machines are brought by technologists to the comfort of their home. This is a great option for people who are immunocompromised and do not want to enter any health care facilities from fear of getting sick. Artificial intelligence systems are becoming popular with more research becoming available. Radiologists are able to get some workload relief with these systems sifting through images. AI is able to alert radiologists of abnormalities identified so patients are receiving vital care sooner than usual. MRI technologists can use AI systems to help determine where the scan parameters need to be in order to scan the patient quicker. PET scans use AI to monitor the progression of illness. If facilities have this software, they are able to monitor if tumors are growing or shrinking as a result of treatment. MIP images are an addition to CT and MRI angiography scans that create better resolution images for radiologists to review. This software finds the most pixelated images and creates images focusing on just these parts of the image. Three-dimensional imaging takes pixels of the axial images from a scan and stacks them on top of each other to create a three-dimensional look. These are often used for surgical mapping, localizing foreign bodies, and identifying the specifics of a fracture. Electronic ordering makes it easier for orders to be checked for errors and to be changed should they need to be. They also allow for better translation for registration to be able to read the order written by the doctor. C-arms are used in surgery to assist surgeons in localizing the area of the body they want to see. Orthopedics use the c-arm to reduce fractures and to add plates, pins, and screws. Other surgeons use c-arms as well. Fluoroscopy is used in the radiology department with the assistance of the radiologist. Patients receive swallowing tests, barium enemas, arthrograms, myelograms, and even bladder fluoroscopic exams. Automatic stitching programs allow for the attachment of multiple radiologic images to make one long x-ray. This is usually used on lower limb x-rays as well as scoliosis studies.

There are more changes to radiology than I can fit into this paper, but I will focus on the ones that I think made the most impact. The patient is the biggest benefactor when these innovations are made is the patient. The changes that come about reduce errors and create a safer and more pleasant experience for the patient. Digital imaging, portable x-rays, artificial intelligence systems, MIP/three-dimensional reconstructions, electronic ordering, surgical imaging equipment, fluoroscopy, and automatic image stitching all invoked change that created a better imaging experience for the patient, the technologists, and the ordering physicians.

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Introduction

Technology plays a major role in every aspect of heath care. With each new invention, the medical community is able to utilize these to their advantage while performing their daily duties. New advances have drastically changed the way people receive treatments. Each innovative change results in providing efficient, cost effective, and better-quality care. Even though the purchasing of new equipment is not at all cost friendly, the outcome of having this upgraded technology far outweighs the expense. Considering radiographs and multi-plane scans are usually a starting point for physicians when trying to determine the source of an illness, it is important that the machines are as efficient as possible. Newer radiologic systems prove to decrease the time between patients having the x-ray taken and the physician receiving a diagnosis.

As a radiological technologist myself, I understand how adapting to changes and incorporating new radiological inventions is crucial in providing the best quality images and ensuring the proper diagnosis is made by the radiologist. Among the many innovations made to the radiology field; digital imaging, portable x-rays, artificial intelligence systems, MIP and three-dimensional reconstruction, electronic ordering, surgical imaging equipment, fluoroscopy, and automatic image stitching have all been great additions to increase image quality and allow for better patient care.

X-rays Invented

In 1895, after nearly two months of consistent work, Wilhelm Roentgen finally reported his discovery of x-rays after he studied a type of radiation that is able to move through objects of varying thicknesses (Tubiana). He decided to call them x-rays due to the fact that he did not exactly understand their nature. One of the earliest radiologic images created was of Roentgen's wife's, Bertha, hand. This image demonstrated how radiation passes easily through soft tissues, but metals and bones are left visible (Chodos). His findings started an uproar of interest in x-rays. Within months, physicians began to use x-rays on patients to study their bones and organs. In less than a year, diagnoses and therapy using x-rays became a routine part of medical treatment. Even scientists such as Thomas Edison worked to perfect the discovery, creating his own invention of the handheld fluoroscopy (Chodos).

Bertha Roentgen's hand x-ray, November 8, 1895. (Chodos, p.1)

<u>Screen Film Radiology</u>

When x-rays were first discovered, they were performed using a screen film printing (Lakhwani). This is similar to how photographs are developed. The x-ray is produced when an exposure from the tube is registered. Afterwards, the plate is taken to a dark room. Here the film is run through a developer. It is important that the dark room is actually dark. No white light should fall upon the film until after it is developed, or the x-ray could potentially be damaged. The only light in a dark room comes from a red lightbulb in the corner opposite the developer. The entire process takes roughly ten minutes to complete. The cassette then has to be reloaded while still in the dark room with a blank film. These are secured from a heavy pull-out drawer that must stayed closed when the door is open in order to keep the integrity on the undeveloped film. If white light reaches the unexposed film, the entire stock has to be destroyed due to not knowing whether or not the film is still usable. This can be an extremely costly mistake. Having digital radiology eliminates all these potential mistakes.

Opened Screen Film Cassette (Christman, p.1)

Digital Radiology

Digital imaging, in my opinion, is the greatest invention and change to radiology. Digital detectors have pixels that can catch and release images, making them reusable. On the other hand, screen film x-rays are one time use only. It is much like taking a picture on your phone. Within milliseconds you have an image that is stored electronically. With new technologies, x-rays are made when the digital detector registers an exposure and image is ran through a computer system that processes the image within seconds. The fact that we can see images within mere seconds verses several minutes can actually save lives. If a patient has a pneumothorax, a condition where one or both lungs are collapsed, it is important that they are treated promptly (O'Connor). These can happen either spontaneously or due to an accident, like a fractured rib puncturing the organ. An illness like this requires a chest tube to drain whatever substance is causing the lung to collapse, whether it be fluid or blood (O'Connor). After the chest tube is placed, a repeat x-ray must be taken to make sure the tube is in proper position. If placing blindly, the lung parenchyma can be damaged and worsen the patient's condition. This is why digital imaging becomes vital for this patient's health. If the image is not positioned correctly using screen film radiographs, it could take much longer to get an appropriate reading. Radiologists want to see the entire lung field to see how extensive an illness is. If the film is positioned behind the patient too far left or too right, or too high or too low, you have an increased chance of clipping the opposing side. With digital imaging, the x-ray is almost immediately available for review and repeat images can be made and reviewed as soon as the correction is made.

Konica AeroDR HQ Digital Cassette (Konica, p.1)

PACS System

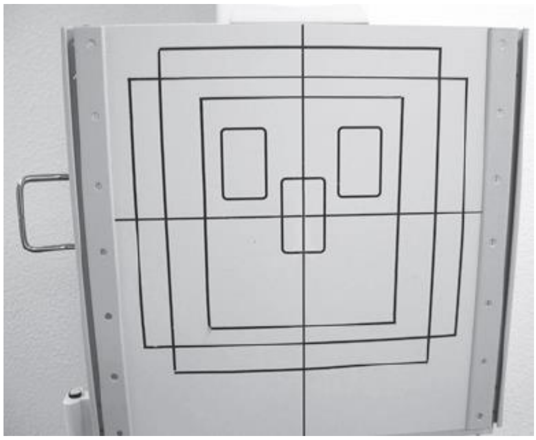
Digital images are stored in a system called the picture archiving and communication system or PACS (Strickland). This makes them easy to access across multiple facilities that also use PACS. This was not an option for screen film. The only copy you had was a hard film copy. Unless an office requests the image to be mailed to their facility, the only people who are going to see the x-ray is the facility where it was taken and housed. A great benefit from PACS is that fact that the images cannot be lost, misfiled, or stolen (Strickland). Once saved, they will be accessible forever. Issues were raised when many hospitals in the year 2000 reported that twenty percent of their films were missing when requested from them. With PACS, images can be viewed in multiple locations at the same time, however, with film radiology only the location of the x-ray is available to see the image . Furthermore, having comparison images is important when radiologists are reading new images. This is because if they see an abnormality, they can use previous images to determine whether this is an acute illness or something chronic (Strickland). If the illness was present on the previous image, the radiologist will know this most likely is not causing the new and current symptoms. With PACS, images can be pushed via Power Share or some other system and received in about ten minutes time. This feature allows for both the comparison ability and also so images that are not having to be repeated due to lack of access.

Eliminating paperwork for radiologist was a big adjustment for radiologist. Before PACS, radiologists were handed the requisition that listed who the patient was, the examination that was being done, and symptoms the patient is currently experiences (Ralston). The requisition signaled to the radiologist that the examination is currently unread and ready for dictation. The radiologist knew that the examination was his to dictate because he was the only one with the requisition. With PACS, the worklist is consistently updating radiologist on what examinations are waiting for a read as well as showing examinations that are currently being read (Ralston). PACS also groups unread examinations into areas of specialty if they are needing specific attention of a trained radiologist. In order to read examinations such as mammograms, radiologist must have specific training and keep this training up to date. With PACS radiologists are also able to store notes and comments that are not included in the report for future dictations (Ralston).

Automatic Exposure Chambers

Another benefit of digital imaging is the fact that these systems contain automatic exposure chambers (Sterling). This is a density control system that terminates when a certain amount of radiation has been reached on these areas. These can only be used in the x-ray room when imaging at the wall bucky or using the table bucky. There are three chambers on any digital equipment, and they can be engaged at different times but the top two and bottom one are generally never used at the same time. There are two toward the top, one left and one right, then there is one on the bottom in the center. More exposure will pass through items of lower atomic number (Sterling). An example of this is lungs. Lungs are full of oxygen which have the atomic number eight (Ptable). Bone however is composed of calcium, which has an atomic number of twenty (Ptable). This means when an x-ray of the chest is taken (the two top chambers will be engaged), the exposure will be less because the radiation will pass through the lungs quickly and the exposure will terminate (Sterling). In contrast, if an x-ray of the lumbar spine is taken (the lower middle chamber will be selected) the exposure will be higher because it takes more radiation to pass through bone. The result is less radiation to the patient.

When using screen film radiology, exposure is determined by radiographer performing the examination. So, if a patient is larger, you have to try and calculate the amount of exposure you want to attempt to use. If this calculation is incorrect and the image is suboptimal, a repeat image may be necessary. This increased exposure to the patient and takes longer to receive a proper diagnosis. Automatic exposure chambers help to determine how much radiation will be needed so that the number of repeat images due to incorrect exposure are reduced. This is important because too much radiation can lead to side effects to health. X-rays are labeled as a carcinogen by both World Health Organization and the United States government (Newman). This is because scientists worry about the lasting effects of too much radiation.



AEC chambers – indicated by the smaller boxes, 2 at the top and 1 in the center (Lagdimi, p.1)

Radiation Side Effects

When radiation passes through your body, it actively changes DNA (Newman). This is why it is sometimes used as a way to cure cancer. Healthy cells can repair breaks in DNA better than cancerous cells can (Majeed). Cancerous cells are targeted by radiation therapists and blasted with a large dose of radiation. This has proven successful in killing cancer cells. It is important however that the therapist target only the cells they are wanting to eliminate and minimize the damage to the surrounding healthy cells. Studies estimate that 0.4 percent of cancers in the United States may be due to computed tomography scans (Newman). However, this number is expected to rise due to the fact that computed tomography utilization is on the rise. The details received from computed tomography scans far surpass using plain film radiology, so doctors tend to choose this type of examination over x-rays (Newman). We also receive radiation from our environment as well. The most common exposure is radon, which is mostly found in soil and water (Newman). Pilots and airplane crew members receive increased radiation from cosmic rays being at a higher altitude more often (Newman). Compared to natural radiation exposure, a computed tomography of the head is equivalent to 243 days of natural background radiation (Newman). Although the risk for side effects is seemly low, patients should advocate for themselves and make sure the examination ordered is something that would help diagnose their current illness. Especially parents who have children receiving any type of imaging. Children are rapidly growing which means their DNA is more susceptible to radiation effects.

Acute side effects include reddening of the skin, fatigue, loss of appetite, nausea, vomiting, and headaches (Majeed). These symptoms are rare to occur due to diagnostic imaging. Patients who are experiencing these types of side effects are most likely receiving an examination that requires a high dose of radiation usage. Radiotherapy would be the ideal place that these symptoms are caused by radiation exposure (Majeed). Long term effects include neurocognitive effects, cerebrovascular disease, ischemic heart disease, chronic diarrhea, and ulceration of the gastrointestinal system. Though the chances are between 0.2 % and 1 % of developing secondary malignances from radiotherapy, cancers like breast, lung, stomach, bone, bladder, thyroid, and leukemia can occur from long term exposure (Majeed).

Portable Radiology

Portable radiology is another invention that significantly changed the x-ray field. Sometimes patients are too ill to be transported to and from radiology for imaging. Although using a system with automatic exposure control provides for better quality imaging, portable radiology is beneficial for patients who cannot be moved. Portable radiology became very popular during the uncertain times of COVID-19, when the health systems were trying to stop the spread of this illness (Zubair). Portable x-ray machines have also significantly changed overtime. They too relied on screen film imaging before digital radiology was invented. Issues developed if you had to travel to the opposite side of a facility to take an x-ray and then travel back to the radiology department where the dark room is located to develop the radiographs that are undiagnostic. If the images were in need of repeating, you would have to replicate the process until the x-ray image is of good quality and contains all the allotted anatomy. Portable radiology is used more frequently for examinations that are for line placement. If someone is intubated, radiographers go to the room the patient is residing in and slide the film beneath them before exposing the x-ray.

DXR Portable X-ray Machine (Carestream, p.1)

Lead Barriers

It is important to watch your surrounding when using portable radiology so people that are not the patient do not get unnecessary radiation exposure. All rooms in an x-ray department have led-lined walls and doors. These all have to be 20 to 23 cm thick depending on the location of the x-ray table (Lakhwani). When imaging portably, there are no walls to protect the surrounding patients, employees, or yourself. In these situations, time, distance, and shielding are your best friends. Time stands for the amount of time it takes to make an exposure. If a patient is larger, it going to take more time for the radiation to properly penetrate the area of interest. In these cases, a grid should be applied to the x-ray plate in order to catch some of the unused radiation that will bounce off the patient. Radiologic technologists should also limit the amount of time spent in areas where the radiation tends to be higher (OSHA). Distance I was taught, is the most important of the three. It is recommended that anyone not being x-rayed distance themselves at least six feet away from the portable x-ray machine (OSHA). The exposure cord on the portable machine is coiled and stretchy like old phone cords so that it gives the operator the appropriate leverage to maintain a safe distance. X-rays do not travel for long, and studies show that most radiation is depleted within six feet of exposure. As distance increases, exposure then decreases. The *inverse square law* states that increasing the distance from the source of radiation by a factor of two will result in a decrease of dose by a factor of four (OSHA). Shields are used to cover vital areas that are more sensitive to radiation or areas that need more protection. These areas are reproductive organs, thyroid gland, and breast area.

It is very important that any pregnant women be distanced from the exposure. This keeps the baby safe while it is rapidly developing. Studies are not conclusive on what exactly could happen to a fetus, but the first trimester is when the baby's DNA is developing the most and keeping distance from radiation could help prevent mutations (OSHA). When increasing your distance by two, the exposure is reduced by four times what the patient is receiving. It is also important to remember, when using portable radiology, the source to skin distance should be no less than fifteen inches.

Lead Shields

Shielding is a great way to keep radiation from any area that is not receiving radiation. This especially applies to reproductive organs, especially in females since they are born with all the eggs they will possess in their lifetime. Shielding can only be done if the required anatomy is not obscured. So, when imaging the pelvis or bladder, the reproductive organs must remain unshielded because the led will completely block out the organ on the x-ray. There are several types of shields used in radiology. The shields used are composed of lead since lead has an atomic number of eighty-two making it very dense and able to stop gamma rays and x-rays (Lakhwani). There are thyroid shields which clasp around the neck area. Applying a thyroid shield while performing mobile examinations can help the technologist reduce radiation by fifty percent to the thyroid area (Lakhwani). This is very important since the neck receives approximately ten to twenty times more exposure than the trunk of the body. The thyroid has proven to be sensitive to radiation(OSHA). Using a thyroid shield has shown to decrease radiation exposure to this area by fifty percent (Lakhwani).

There are also lead aprons which generally protects the breast and the reproductive organs. These are mainly worn during fluoroscopy or surgical imaging. However, sometimes when performing portable x-rays, the patient will need to be "held". This term refers to when an employee must help the patient maintain the position needed for the x-ray. Generally, this only happens when x-raying children or unconscious patients. In these cases, lead aprons should be worn for the technologist protection. Lead aprons should be lined with at least 0.5 mm lead thickness (Lakhwani). Wearing these aprons have proven to reduce ninety nine percent of radiation exposure to the trunk of the body. There are front coverage aprons that just cover the anterior part of the body (which should always be facing the source of radiation). There are also full wrap aprons that go all the way around the body and overlap, like a robe. All lead aprons must cover from neck area to approximately four inches above the knee (Lakhwani). Gonadal shields are another type of barrier used by radiographers to protect patients from unwanted radiation. These are the smallest shield used in x-ray. It is generally a tiny triangle placed over a female's ovaries or a male's testes. Technologists and radiologists whose hands are constantly under direct radiation are encouraged to wear lead gloves (OSHA). However, when using fluoroscopy, wearing these gloves while in the primary beam can cause the equipment to increase radiation output due to the higher atomic number of lead compared parts of the body (OSHA). This causes higher exposure to everyone in the room during the examination. Safety goggles are also available for use to protect from radiation induced cataracts. These goggles are lead lined and opaque to reduced direct eye exposure (OSHA).

Lead Apron (Burlington Medical, aprons tab, p. 1) Thyroid Shield (Burlington Medical, other wearables tab, p.1)

<u>Checking for Defects</u>

It is very important to inspect the lead aprons yearly. Any holes or compromises in the lead should result in disposal as this can affect its effectiveness (Lakhwani). These holes can be from wear and tear, misuse, or improper storage (OSHA). To check for defects, technologists should apply fluoroscopy and run the image detector over each area of the shield looking for any white spots that would present a hole (OSHA). For a professional appearance, aprons should be cleaned regularly to prevent the buildup of germs, blood, or barium. It is important to store lead aprons on hangers that prevent any sagging on the ground. Folding of lead shields could lead to potential tears (OSHA).

Dosimeters

Dosimeters are worn by several different individuals who are regularly exposed to ionizing radiation for their jobs (University of Pittsburg). This monitor measures the approximate amount of radiation they receive. There are many different types of dosimeters available for these employees to wear. The whole-body dosimeter keeps track of exposures to the head and trunk of the body (University of Pittsburg). Whole body dosimeters are generally worn at the collar and outside of any lead shields being worn. Ring dosimeters are worn mostly by nuclear medicine technologists and measure the exposure to their hands (University of Pittsburg). The ring monitor should be worn on the dominant hand that will likely receive the most radiation exposure. Fetal monitors are worn by pregnant women who have declared pregnancy (University of Pittsburg). There monitors are worn at the waist level and should be worn beneath lead shields in order to receive accurate readings the fetus could be getting. Monitors are changed in one month, three-months, or one-year periods depending on the type of monitor the facility chooses. In the image below, the monitor on the left is changed at the beginning of each month (Landauer). The monitor shown below on the right is only changed one time a year. Supervisors should ensure that employees under their leadership change their monitors within the correct time frame to guarantee accurate dose readings. It is important that dosimeters are not stored in areas of radiation use (University of Pittsburg). Also, make sure that your monitor is worn by you and no one else. You should not lend your monitor to any other employees. There is an annual maximum permissible dose that employees are allowed to reach (Park). This limit is set by the National Council on Radiation Protection. The whole-body exposure limit is 5 rem per year

(Park). If this limit is reached, and it rarely ever does happen, the technologist must take the rest of the calendar year off.

Luxel plus monitor (changed once a month) (left image, Landauer, p.1)

InLight monitor (changed once a year) (right image, Landauer, p.1)

Portable CT

Though I have never seen or used one, there are also portable computed tomography machines. These allow assessment of a patient's brain in their room, thus saving time and limiting transfers that can hurt either the patient or the employee doing the lifting (Zubair). Portable computed tomography scanners are a newer invention, but they have shown to be safe and provide diagnostic quality images. Portable computed tomography scans can save critical patients who need imaging of the head approximately fifty minutes of time (Zubair). This is especially useful for patients who are intubated or suspected of stroke (Rumboldt). Computed tomography machines will let off more radiation due to the fact that they produce multiplanar radiographic images. Practicing shielding and distance is very important in not developing side effects of too much radiation exposure (Zubair). The CereTom scanner is majorly smaller than stationary machines. It can be used to perform CTs of the head, both with and without contrast, computed tomography angiography, and perfusions (Rumboldt). Tomoscan is one type of scanner that has a gantry and multi-section detectors. It also has a table that comes off and goes back on, making it able to perform full-body scans (Rumboldt). The xCAT ENT is used during operations of the skull, sinuses, and facial bones. The OTOscan is also a multi-section scanner that is intended use is for scanning ear, nose, and throat anatomy (Rumboldt). Sometimes this scanner can be used to observe soft tissues of the head. Benefits of portable computed tomography scanners are their compact sizes, more cost friendly, decreased time to obtain image, and decreased radiation (Rumboldt). However, they also come with the disadvantage of limitations of kilovolt, milliampere second, and the smaller field of view (Rumboldt).

CereTom portable CT scanner (Rumboldt, p. 1).

Mobile Radiology

Mobile radiology is when equipment is transported to a patient's residence to perform needed examinations. This can be useful for patients who are easily disoriented by environment changes (Toppenberg). Performing the examination in a place they are accustomed can lead to fewer repeats and better images if the patient is calm enough to hold still. Studies suggest that mobile x-rays increase the certainty of hypothesized diagnoses and avoid unnecessary treatments. Performing mobile radiologic examinations also eliminated trips to hospitals. This is dire when a patient is immune compromised. Vising hospitals can cause patients to contract illness that are airborne and also on contact illnesses. COVID is both airborne and contact contagious. Studies done at nursing homes showed that patients were more satisfied with mobile radiology coming to them due to not having to leave their homes as well as not spending hours at a facility to receive the same type of examination (Topperberg). Mobile radiology reduced the need for transportation as well, lessening the burden on the staff at the facility and the transportation company staff as well. Mobile images of chests, hips, extremities, and pelvis were found to have no substantial differences in image quality when compared to the same examinations performed at hospitals (Topperberg). Mobile radiology has also been found to cost similarly to those performed at a facility, having no significant price difference.

Artificial Intelligence Systems

Artificial intelligence is becoming more popular among the imaging field. While in traditional radiology, physicians with vigorous training visually access all medical images for diagnosing and detecting diseases (Hosny). New algorithms with artificial intelligence are being perfected to automatically recognize patterns throughout the image data that indicate if specific illnesses are present (Hosny). Features with newer advanced technology has the ability to identify three-dimensional shapes of tumors. It is thought that more precise and quicker assessments of imaging can be made if artificial intelligence is integrated into the facilities workflow as a way to assist radiologists (Hosny). Artificial intelligence can help when diagnosing lung cancer. With the correct artificial intelligence technology, help identifying whether or not lung nodules are benign or malignant can be provided. It also can artificial intelligence in identifying cancers in abdomen and pelvis CTs and MRIs, polyps seen on colonoscopies, and mammography (Hosny). Artificial intelligence has also been found useful in monitoring the effectiveness of radiation therapy treatments to help alter future treatment plans when needed.

AI Assisting Radiologist

Having artificial intelligence systems can help assist radiologist process large amounts of images in a shorter amount of time (GE). There is an innovated system in mobile radiology that enables artificial intelligence systems to prioritize examinations in order of significance to indicate a possible critical finding. Artificial intelligence can also help orientate images to their correct positions so that when they are sent for radiologist review, they are correct and ready to diagnose (GE). This saves time for both the technologist and the reading physician. There are artificial intelligence systems that will call attention to low image qualities, like clipped anatomy or wrong techniques, so technologists know sooner that an image should be repeated, and the patient does not have to wait as long to get a diagnosis. Having a system that immediately points out images that are undiagnostic would be something I would love to have at my hospital. Coupled with the fact that radiologic images look different on PACS, which is where the radiologists tend to read from, than they do in the x-ray room or using the portable machines, this feature benefits everyone's time that is involved with the patient's care (GE).

MRI Advantages of AI

Artificial intelligence has also been useful when examining images of MRI brain scans (GE). Structure images of the brain are used when diagnosing tumors of the brain, as well as strokes. Functional imaging is used to evaluate cancers and metabolic diseases (GE). MRIs tend to be lengthy examinations. Even with the newest updated system, the fastest time you will finish an MRI of the brain is fifteen minutes with a cooperative patient. That added to the noisy, confined space of the tunnel can cause patients to refuse finishing an examination. Artificial intelligence systems help to align MR scans for brain scans and identify the area of interest (GE). This cuts back on the technologist having to manually set the lines of the places they want scanned. This results in uniform scan alignment so that diseases can be tracked to an exact location, even if the scans are performed months apart from one another (GE). Having this smart technology also helps to reduce scan time since the setup is much faster.

Artificial Intelligence Methods

There are two methods of artificial intelligence technology that are used in radiology today (Hosny). The first utilizes features that are defined by mathematical equations. This figure involves learning models that are tutored to classify patients to help assist clinical decision making (Hosny). This method is unable to adapt to imaging modalities that vary quickly in their signal to noise characteristics such as computed tomography, PET, and MRI. The second method of artificial intelligence used in radiology is deep learning (Hosny). This is becoming the more popular option, gaining more attention recently. These algorithms can spontaneously learn diseases without the need for previous indication by radiologists. Deep learning can impulsively identify characteristics of human tissues and quantify the phenotype with enough example data (Hosny). Deep learning methods of artificial intelligence can learn complicated data depictions, robust against variation that is not wanted, and can be used in a large variety of clinical examinations. This is the image of what skilled radiologists can do in the sense of identifying diseases and recognizing if these parameters are of significance or not (Hosny). Deep learning techniques have proven to be accurate when compared to radiologists for segmentation as well as detection of diseases in both ultrasound and MRI.

Using AI in PET Scans

In reference to PET-CT, deep learning had higher sensitivity to abnormalities but lower specificity when compared to radiologists (Hosny). With the influx of COVID deaths, more radiologists retired in the last few years than facilities have been able to replace. Having artificial intelligence can reduce the stress and workload for any radiologist at a given facility (Hosny). Simpler, uniplanar examinations can be read by artificial intelligence and reviewed by radiologists if questions arise. The radiologist systems that are utilized now has lengthy turnaround times because the workforce is so depleted at the moment (Hosny). artificial intelligence algorithms can help prioritize this worklist so that any examinations that are deemed critical go first and are not being lost at the bottom of a long list of unread examinations.

MIP Images

Maximum Intensity Projections, also known as MIP, is used in computed tomography to create enhanced three-dimensional images after contrasted angiography scans (Prokop). MIP images are most useful when the area of interest is contrasted sufficiently higher than the surrounding tissues (Prokop). For this reason, MIP reformats are mainly used when imaging arteries like the pulmonary or aortic arteries during examinations that are referred to as Computed Tomography Angiography or CTA (Rybicki). Because blood leaves the heart via arteries, these are the first to opacify. As soon as the arteries of interest have efficient contrast opacification, the computed tomography machine immediately scans (Rybicki). This ensures that only the arteries are enhanced, making it simple for MIP software to differentiate what areas need to be excluded (Prokop). MIP images are routinely cut into one-millimeter slices in axials, sagittal and coronals to allow for more visualization of anatomy and to provide greater detail of any diseases.

MIP image from a contrasted computed tomography of the chest demonstrating lung nodules in a patient with lung cancer (Gruden, p. 1).

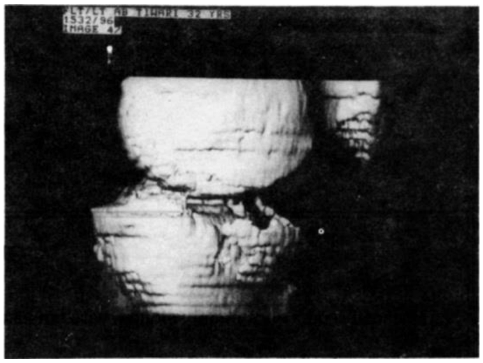
Computed Tomography Angiography (CTA)

Computed tomography angiography (CTA) scans require an intravenous catheter to be inserted. With these types of scans, contrast is injected at a quicker rate than other traditional scans, requiring a lager IV. Once you have your initial scout images, you then set your ROI (region of interest) in the artery of concern (Rybicki). The contrast will inject until it reaches the set Hounsfield unit, the unit of measurement in computed tomography that determines proper opacification to conduct a diagnostic CTA scan. Once that number is reached, usually ranging between 120-180, the final scan is conducted, and the patient is free to go. The machine has set algorithms that will automatically make the MIP images for the radiologist to view (Rybicki). Since the scan is set to highlight the arteries, the algorithm will pick out each pixel that is in the range of Hounsfield units selected and make those pixels more pronounced for a more defined view of the artery of interest.

The use of computed tomography angiography can eliminate the need for hearth catheterization surgeries since they are able to detail the flow of blood throughout major arteries (Radiology Info). They are beneficial for patients due to how quickly they can be performed, while remaining less invasive than conventional angiography. Coupled with the fact that computed tomography angiography does not require patients to undergo sedation or anesthesia while also being more cost effective than catheter angiography, it is usually the first course of action when it is not contradictory (Radiology Info). However, before contrast administration to perform these examinations, technologists need to ensure the patient has not had a previous reaction to anything iodine based, as well as ruling out any possibility of existing renal failure that could worsen with contrast injection. Though severe reactions to iodinated contrast is extremely rare, facilities are required to keep medications close by, with the knowledge on what to do to resolve any complications (Radiology Info). Another limitation when performing CTAs involves patients with larger body habitus not fitting into the computed tomography gantry opening or exceeding the table's weight limit.

Three-dimensional Reconstruction

Three-dimensional computed tomography has been used and constantly perfected since the 1980s (Ram). The software is programmed to take plain contrasted axial images and make representations that are three-dimensional. This is done by the choosing of pixelated areas that are a set attenuation level (Ram). The pre-determined Hounsfield unit is set so that only areas of that set level will be included in the post-processed image. The selected axial images (which are "cut" from top-down) are stacked on one another to create the new three-dimensional image (Ram). Because lower levels pixels are not included in the three-dimensional image, this limits which areas of the body these reformats can be used for. The main use for this algorithm is for creating three-dimensional bone images or contrast enhanced artery images (Ram). There are surgical mapping scans that will create three-dimensional models of current bone anatomy and make suggestions on what size prosthetic is needed for a joint replacement. Successful three-dimensional imaging also provides a better view of congenital defects and the precise shape and size of fractures to help with surgical planning (Ram).



3D image the knee joint revealing a compression fracture (Ram, p.1).

CT Three-dimensional Limitations

There are some limitations to three-dimensional images that could render the scan useless if they occur (Ram). Patient motion would cause streak artifacts in the image, making it look blurry. If the axial slices are too thick, they can cause raster lines. Also, any dense objects on the patient like rhinestones, dental fillings, necklaces, etc., could cause streak artifact on the image. One way to reduce motion is by patient communication (Ram). Explain to the patient exactly what occurs during the scan as well as what is expected of them during that length of time. Thoroughly question and remove any external objects or clothing that may cause preventable streak artifact. Most computed tomography scanners allow for post processing of images. Using this software, technologists should be able to request thinner slices from previous examinations, eliminating the need to replicate examinations (Ram).

Three-dimensional Images in Ultrasound

Although a vast majority of diagnostic ultrasounds are performed using two-dimensional images, three-dimensional images are also used in ultrasound (Fenster). Three-dimensional ultrasound is sometimes preferred over other imaging modalities due to lower cost and the fact that obtaining images does not require the use of radiation (Huang). However, ultrasound is very sensitive to movement and motion, so technologist need to know what breathing techniques are needed for each examination. When used in obstetrics, three-dimensional ultrasounds are useful in diagnosing of irregularities of the baby's face (for micrognathia and cleft lip), rib abnormalities, fluid buildup, and atypical spine curvature. Ultrasound three-dimensional images are also used to aid in biopsies (Fenster). If a prostate is being examined, the transducer is inserted into the rectum for optimal three-dimensional views. This allows the physician to precisely place the needle into the area of concern. Transrectal three-dimensional ultrasounds also aid in positioning of prostate implants (Huang).These images are not possible to obtain using two-dimensional ultrasound.

Cardiac sonography also uses three-dimensional ultrasound to create pictures of the heart (Greenleaf). Using these types of echocardiograms allow scientist to measure image features, identify anatomy, separate tissues from each other, and produce three-dimensional data interpretation. These images allow views of the atrial septum and ventricular chamber, with the option to add color to enhance the understanding of the anatomy (Greenleaf). These three-dimensional heart images can provide cardiologists with information on blood flow and ejection fractions to properly diagnose patients with ischemic and/or congenital heart disease (Huang). The use of three-dimensional ultrasound can also be beneficial in surgery, allowing for less invasive resections of gliomas and brain tumors. Using three-dimensional ultrasound to image small joints can provide physicians with details of articular and periarticular structures, useful for diagnosing patients with rheumatology (Huang). These images can demonstrate bone erosion, enthesitis, and tears of tendons. These advanced ultrasounds can also visualize aortic wall strains and aortic aneurysms while also aiding in the stent grafting to correct these issues. Additionally, urologists use three-dimensional ultrasounds to view the pelvic floor, urethra, and levator ani when looking for the source of urinary incontinence and pelvic floor dysfunction (Huang).

2D ultrasound image vs 3D ultrasound image (Boehrer, p. 1)

Electronic Ordering

With the addition of electronic ordering, the orders are understood with more clarity. Written orders are often not legible, especially when written by the doctor themselves. If an electronic order is put in incorrectly, it is much simpler to correct then if the order is paper. If there is an error with electronic orders, it usually takes a single call to clarify what the physician wants. Studies conducted by facilities switching to electronic orders have shown that computerized physician order entry (CPOE) improve indication quality (Pevnick). If the ordering physician puts an order in for imaging that requires any contrasted material, the physician will be notified immediately of any contradictions that may prevent that patient from receiving the contrast. Also, patients with low renal function should not be administered any contrast due to the possibility of that worsening. Contrast is excreted from the body by the urinary system. If a patient has a history of renal disease and the physician orders intravenous contrast, they are alerted of this and encouraged to wait for the patient's renal function panel to result before the examination is conducted. If the ordering doctor requests an incorrect examination, like computed tomography with contrast media for a patient with flank pain and potential kidney stones, any technologist familiar with how contrast works would question that order. Since the ureters absorb contrast because the kidneys dispose of contrast after receiving it, they usually become white and radiopaque. This could obscure a kidney stone that is present in the ureters since they too are white on the scan. After confirming the correct examination, the technologist can either change the examination to the correct choice or have the physician do it themselves in a process that takes less than five minutes. Studies also resulted in an increase in background information for the radiologist when reviewing images (Pevnick). Where they used to only receive sign and symptoms with paper orders, they now receive a more detailed history with CPOE.

Paper Orders

In the past, physicians wrote the imaging examination indication by hand on paper before being handled by multiple parties (Pevnick). Clinicians are often faced with time crunches, so they rush between patients in order to treat everyone that comes through. This could result in little, or no examination reasoning being provided (Pevnick). Although there are order forms with many checkboxes for providers so more information is provided, they still have information missing that could be pertinent to the examination or technologist performing the examination. The common issue among paper orders is when physicians have to fill out blank paper order forms (Pevnick). The most popular use of paper orders comes from specialists who have patients that live near rural hospitals. Most smaller hospitals do not have physicians outside of emergency and family medicine. For this reason, patients have to travel to receive any kind of specialist opinions. Any orders received from the specialist will likely be a paper order since they will be out of network. Also, competitors of different facilities are considered out of network and require paper orders as well. If a patient prefers their examination to be performed outside of their providers network, a paper order is required.

These are not easy to correct if the order is wrong. It is important to double check all orders that come in as faxes due to the fact that several people, scheduling, precertification, registration, handle the order before the patient reaches radiology. This could cause potential issues with the order being scheduled wrong or checked in wrong. In order to ensure the patient does not receive unnecessary radiation exposure and insurance pays for the examination, technologists should compare symptoms to the examination being performed. If the order is wrong, technologists have to track down the provider or a nurse in that office and request a new order be faxed to their facility. This is a lengthy process as faxes are not always reliable to send. If the network is down, patients have the potential of having to reschedule until the correct order can be sent. Even something as simple as an order for the right foot with complaints of left foot pain will require an entirely new order before the examination can be performed. It is very inconvenient for both parties as it takes the technologist away from the floor to try and resolve the issue as well as the patient spending excess time at the facility. All of these issues are avoidable with electronic orders.

Paperless Improvements

With the elimination of paperwork, many people benefited from less waste. For the staff who stored the film, the introduction of PACS was a huge improvement (Ralston). Films and the jackets they were stored in were disposed of after ten years of switching over. Although at the beginning, some paperwork still had to be kept. For instance, patient consents to contrast administration, pregnancy declinations, and ultrasound worksheets were kept until newer systems were created that ridded of those too. Now these files are scanned into the system and then disposed of the same day by the technologist completing the examination. Some facilities still choose to file the paperwork and keep it on hand, but for the facilities that switched over to be completely digital, there has been great success reported by the record managers (Ralston).

Radiologist have used paper for two main reasons, paper orders and printed schedules of the fluoroscopy examinations they will have to perform during the workday (Ralston). Before, technologists would have to pull prior examination reports, background information, and clinical information from the patient's film jacket. Radiologists now have a paper-free work environment. The examinations that are to be read can be found on the PACS system. Also available to them is any previous study the patient has had since switching over to the electronic storage systems (Ralston). Often times if patients have had examinations at a facility on a different storage network, the patient can get the images on a disc for medical records to upload, making it available for radiologist to review. Sonographer worksheets that the radiologist routinely reviews are upload to the PACS system and stored with the ultrasound images so the need to pass the paper copy around eliminated (Ralston).

Technologists benefit majorly from the use of electronic orders and the PACS system. With older systems, when an examination was requested and ready to be performed, a paper order printed off with the patient's information (Ralston). Today, the order populates on a worklist of whatever system the facility uses. Technologists must still use paper to write down history, get consents, and write examination impressions (ultrasound technologists), but once those are scanned into the system, all these papers can be shredded and forgotten.

Transcription has made huge improvements with radiologist's reports becoming paperless. In the past, transcriptionists had to transcribe a report from the radiologist hard paper copy of the requisition (Ralston). This paper had been passed through many different people, making it prone to rips and tears, as well as the possibility of becoming lost. This would cause delays in the patient's results. With paperless report dictating, transcriptionists receive the radiologist's audio report within seconds of the examination finishing dictation. From there, they listen to the recording and type a report for physician review that will also be stored in the patient's electronic medical record for review in the future (Ralston).

Referring physicians benefit from these reports because they are available immediately after being transcribed and signed by the radiologist (Ralston). Most places have inpatient and emergency room patient results within two hours and outpatient results within twenty-four hours. If a clinician is out of network, majority of the systems are on auto-fax to be sent as soon as the radiologist signs off on it (Ralston). This helps the ordering doctor plan the next steps of the patient's care in an improved timely manner.

C-arm in Surgery

The c-arm gets its name for the shape of the imaging part of the machine that is shaped like a "C". Using the c-arm has proven to dramatically change the outcome of the surgical technique while improving patient outcomes (Joh). A difference between the c-arm compared to traditional radiology is the fact that the radiation comes from the bottom of the C. Whereas x-rays come from the tube that is usually facing toward or above the patient. This is important to remember when providing a shield for the patient. Shields should be placed beneath patients during any case that the lead will not obscure any anatomy that is being operated on. It is also the responsibility of the radiologic technologist to announce to everyone in the room that you will be using radiation during the case and express the importance of wearing a lead apron and thyroid shield. While technologists cannot force anyone to wear lead, it is best to recommend it to everyone in the case, should they not notice the machine. The c-arm keeps track of the time of fluoroscopy as well as the dose received from the radiation (Joh). These have to be recorded somewhere in the case notes, should they need to be referred to in the future. In order to power the c-arm, it must be plugged into the monitor that is then plugged into the wall. The c-arm itself cannot operate without the monitor, both of which take up massive amounts of room. Downfalls of using the mobile c-arm are limitations of precision when performing complicated procedures (Joh). The machine also tends to overheat quicker than imaging equipment, resulting in a cool down period that could lengthen the examination time. Mobile c-arms can also be uncomfortable for the technologists operating the equipment if the machine is not set up properly with the operating table.

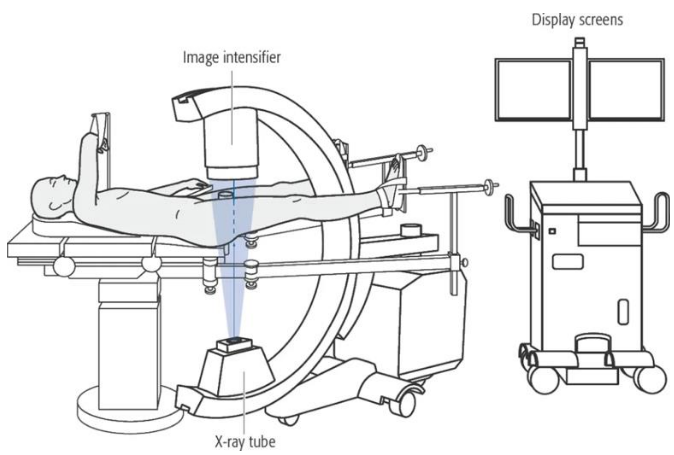


Image of C-arm and monitor (Dresing, p. 1)

Orthopedic C-arm Cases

The main use of c-arms come from orthopedic surgical cases. Operations on fractures, joint replacements, spine surgeries (kyphoplasty), etc., result in better surgical outcomes (Stirton). Orthopedics rely on the technologist to adequately use the c-arm to get the require pictures. It is important that reduction of fractures not easily seen by the naked eye are reduced correctly and any screws or plates inserted are in their correct positions (Stirton). There are issues involving terminology and increased exposure during c-arm use. Every surgeon uses different terms when referring to needing am x-ray or video loop. Technologists should create a standard universal language among all surgeons that makes it clear exactly what type of image is expected (Stirton). This would cut down on the amount of time patients are under anesthesia, as well as frustration among staff, and radiation exposure to everyone in the room. Since there is no guarantee that the same technologist will be present for every surgical case, it is also important that these terms be shared among the department so everyone who operates the c-arm will know what terms to listen for in order to obtain surgical images (Stirton).

Other Surgeon C-arm Use

Mobile c-arms are gaining popularity for endovascular procedures due to their unique ability to move around the patient while under anesthesia (Joh). They are also sometimes used during neurology, cardiology, pain management, nephrology, gastroenterology surgical cases (Joh). General surgeons often use c-arms when performing surgeries that require injecting contrast media. Often during cholecystectomies (surgically removing the gallbladder), if the patient has a history of gallstones the surgeon will inject contrast to ensure there are no stones blocking the biliary trunk (Joh). Complications from obstruction can cause bile backup and liver issues. The c-arm is positioned over the right upper abdomen and cine loops are recorded of the contrast flowing through the biliary ducts. Urologists also use the c-arm when injecting contrast using a retrograde technique to check for blockages from kidney stones. A camera scope is inserted into the urethra and contrast is chased from bladder up to the kidneys searching for any sign of resistance. The surgeon will then use lithotripsy to break down any obstructive stones.

Pain Management C-arm Use

When applicable, pain physicians use ultrasound while performing pain management procedures (Park). This is to attempt to cut down on staff exposure to scatter radiation. More often than not, most still use c-arms as they provide better detail of joint spaces. C-arms project bone structure and shape, as well as the location of the needle when performing injections, with increased precision (Park). Most pain management injections occur in the cervical and lumbar area but can be used in any problematic area. Usually, these injections consist of a numbing agent such as lidocaine and a steroid to help with joint pain. These injections are performed with the hope that patients will rely less on oral pain medication. Some pain management doctors offer pain stimulators that are surgically placed, mostly in the thoracic and lumbar spine, and release electric jolts that help with pain control.

Reducing Radiation Exposure from C-arms

There are several ways to reduce exposure to everyone in the surgical case, most specifically, the patient (Joh). When imaging, put the image intensifier (the big head/top of the c-arm) as close to the patient as possible without compromising the space of the surgeon. This helps decrease any immediate effects from the source of the radiation (the bottom of the c-arm) being too close to the skin (Joh). Each person in the case should use maximum feasible distance from the c-arm.

The main source for occupational exposure is from scatter radiation (Park). This is radiation that is not absorbed by the patient and bounces around after hitting the patient's body. It is the primary cause of medical staff exposure because it bounces in all directions (Park). There are factors that affect how much scatter radiation will be produced during an examination. How thick the area of the body being imaged determines how much scatter will be produced (Park). The thicker the body part, the harder for x-rays to penetrate the patient's body. Obese patients will result in more scatter than lean patients. The location of the x-ray generator will also affect the scatter radiation (Park). The closer you are to the generator, the more scatter radiation you will receive. Anyone on the generator side of the c-arm (the bottom of the C) will have higher radiation exposure.

The c-arms come equipped with foot exposure pedals. To reduce radiation exposure, do not offer these to surgeons and only utilize when they are asked for specifically (Joh). Surgeons will use the foot exposure more since it requires less effort on their part than for them to ask for an exposure from the technologist. Instead of doing cine loops where you must hold down the exposure button, use pulse fluoroscopy whenever feasible (Joh). C-arms allow for collimation the same as regular x-ray rooms do. Use the smallest field of view possible by collimating down to the anatomy of interest. When moving into position, do not use fluoroscopy. Instead use your eyes, and if the patient has not been prepped yet, as well as your hands to properly position c-arm. Do not use the magnification option often as doing so can cause you to clip intended anatomy (Joh). Also, there are two exposure buttons on most c-arms. One is for higher-dose fluoroscopy. This button should only be hit when completely necessary and never for too long as the dose is much higher than the other exposure option.

As previously mentioned, exposure time, distance from source of radiation, and wearing appropriate shields will result in the most protection for the operator and other medical staff. Distance is the most effective means of protection. The inverse square law can help staff understand how gaining more distance decreases their exposure to the c-arms scatter radiation. This law expresses how exposure at a distance from the source of radiation is inversely proportional to the square of the distance. Most law require at least two meters or six feet of distance from the x-ray tube (Joh).

Fluoroscopy

Routinely, fluoroscopy examinations are performed as a workup to show the structural and functional operation of the area of interest (Shalom). Mostly when fluoroscopy is used it is to examine the esophageal pathology of patients. Using contrast, radiologists instruct patients on how to position themselves and when to drink while they study the path of the contrast live (Shalom). This helps to view both the structure and functional operation of the esophagus. Upper gastrointestinal series (UGI) and esophagrams are both noninvasive means to examine the esophagus for benign and malignant pathology. Patients who have complaints of dysphagia, hiatal hernias, or reoccurring reflux are likely to receive an esophagrams or UGI (Shalom). Sometimes if complication arise during an operation, fluoroscopy can be used to examine fistulas that are causing a leak. Videofluoroscopic swallowing studies, more often referred to as modified barium swallows, are performed with a speech pathologist present (Shalom). These are done with the patient in a lateral position while eating and drinking substances that are comprised of different consistencies. These are often performed when a patient presents with aspirational pneumonia (Shalom). Having the patient in a lateral position allows the radiologist to view which liquid thickness is causing the patient to aspirate.

Myelograms are an examination that cannot be replaced by computed tomography or MRI (Shalom). In order for patients to receive a computed tomography or MRI myelography the patient must first undergo fluoroscopy so the radiologist can observe the direction and depth of the needle for contrast injection. Real time imaging is used to guide the needle into the intra-thecal space and observe the contrast as it goes in (Shalom). Due to streak artifacts on computed tomography scans and the surgical limitations of MRI, fluoroscopic myelography is the desired examination for post-operative spinal surgeries.

Benefits of Fluoroscopy

The most beneficial factor of fluoroscopy is the ability to reposition the patient as needed during real time (Shalom). Movement during computed tomography and MRI is not applicable as the images will be compromised. This allows for a great functional view of how a body part is working. Fluoroscopy also tends to have enormously less patient exposure than computed tomography scans do (Shalom). Radiologists are able to use pulse fluoroscopy and focus on one single area of the body. Additionally, fluoroscopy provides physicians with the visualization of functional and focused examinations of specified regions of the body (Shalom). Radiologists are also able to watch barium and water-soluble contrast agents as they travel through the body in real time.

Siemens Luminos DRF Max Fluoroscopy Tower (Siemens Healthineers, p.1)

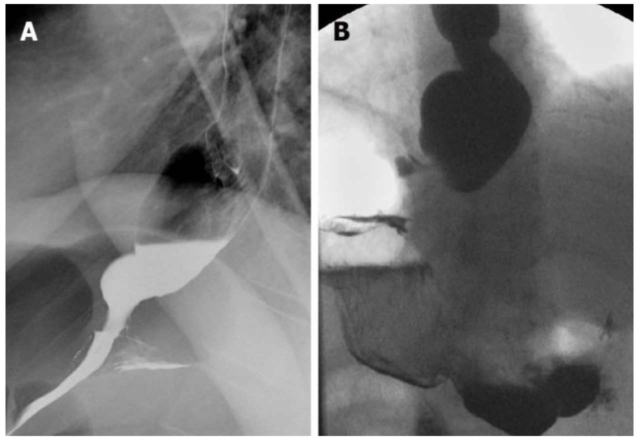
<u>Decreased Fluoroscopy Utilization</u>

Though the amount of fluoroscopy examinations that are performed today have decreased over time, these still remain essential in diagnosing of many disorders (Shalom). With the increased demand for CTs and MRIs, the reduced practice of fluoroscopy is causing issues like insufficient training, fewer staff expertise, and increased costs compared to other modalities (Shalom). Physicians tend to lean toward ordering cross-sectional examinations due to the fact that they are more readily available at all hours of the day. Fluoroscopy examinations require radiologist to perform and interpret the examination, but they generally do not work overnight shifts anymore (Shalom). CTs and MRIs are technologist operated and do not require a radiologist to be present. Another issue with getting these examinations done are fewer radiologists are willing to perform them because they require more effort and usually generate lower reimbursements than reading CTs or MRIs (Shalom). The importance of fluoroscopy examinations is not emphasized in radiology programs because they are practiced less with other preferred modalities at hand. For this reason, many younger radiologists are unable to be assigned to read these examinations.

Esophageal and Gastrointestinal Fluoroscopy

The most popular use of fluoroscopy examinations is to look at the esophagus to see the way food and drink travel as it makes its way to the stomach. Upper GI series and esophagrams are commonly used after surgery to check for leakages that may have occurred (Shalom). These examinations are also often ordered when the patient has trouble swallowing or are having issues with upper abdominal pain. Barium or iodinated, water-soluble contrast is ingested by the patient while the radiologist studies the journey down the upper gastrointestinal tract. Many times, during esophageal fluoroscopy examinations, patients swallow barium tablets to ensure that issues with swallowing medications in pill form are not a problem. Also, if the patient is having issues with repetitive pneumonia, and the physician suspects aspiration to be the cause, a speech pathologist is normally present for fluoroscopy studies call modified barium swallows. For these examinations, patients are fed several different bariums at varying viscosity to make sure they can tolerate each thickness without it traveling to their lungs. Sometimes, patients have silent aspiration and have no idea that the liquids they are drinking are leading to their illnesses. Barium fluoroscopy is also used to rule out achalasia (relaxation of the lower sphincter of the esophagus) as well as esophageal pseudodiverticulosis (small pockets that pouch out within the wall of the esophagus)(Shalom).

When patients are experiencing small bowel obstructions, the physician will often order a small bowel series fluoroscopy examination as a therapeutic examination (Shalom). Patients are either given water soluble contrast to drink or it is injected into a nasogastric tube directly into the patient's stomach. In a lot of cases the contrast will act as a laxative and promote the patient to have a bowel movement. Some indications for small bowel series are to check the transfer time of foods through the stomach and small intestines. For these cases, usually in an outpatient setting, the patient is given barium instead of water soluble. It is important that patients who may have a surgery soon or that has had a very recent surgery involving the gastrointestinal system be given water soluble contrast. This will reduce harm to the patient should there be leakage out of the digestive tract into the body. There are therapeutic barium enemas as well. Patients who have Hirschsprung's Disease will become familiar with these as they deal with issues of constipation very often (Shalom). The water-soluble contrast helps to clear the large intestine of any blockages. Patients who are sent from a post-operative colonoscopy to have a barium enema require the use of water-soluble contrast as well given that the surgeon almost always takes biopsies from the colon during the operation. The same as a small bowel series, if the patient comes in for an outpatient examination, normal barium is used to perform it. These are often completed to assess the structure of the large intestine and to look for any polyps or diverticulum that would be considered concerning as cancerous or susceptible to rupture.



Fluoroscopic barium filled esophagus, distal end (Shalom, figure 1, p.1)

Spinal Fluoroscopy

Invasive examinations are sometimes done through fluoroscopy when the chances of injuring something vital is present. This allows the physician to visualize, in real time, the needle advancing into a sensitive area. Myelography is an examination that is performed in the fluoroscopy suite before sometimes being sent to computed tomography or MRI for additional images (Shalom). The myelography examination is performed when there is concern for a cerebrospinal fluid leak. Radiologists observe the needle as it is guided into the specified spinal area, where contrast is then injected into the intra-thecal space (Shalom). Although other types of fluoroscopy examinations are used much less than they were with the older generations of radiologist, the myelogram is still preferred for post-operative examination of the spinal canal due to the computed tomography and MRI limitations, therefore this skill is still essential for newer radiologists entering the field (Shalom). Lumbar punctures are another spinal examination that is performed under fluoroscopy. For this examination, a needle is guided into the spinal canal and spinal fluid is extracted and send to the laboratory. Lumbar punctures are performed when meningitis is suspected.

Fluoroscopy image of a needle guiding and injecting contrast into the spine at varying levels (Shalom, figure 7, p.1)

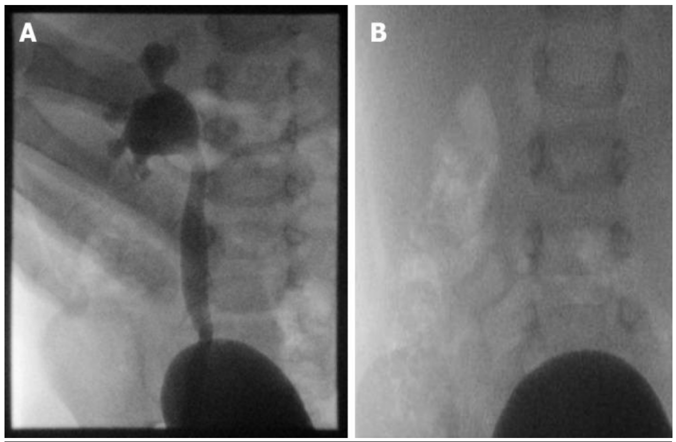
Reproductive Fluoroscopy

Hysterosalpingograms are fluoroscopic examinations that are performed when issues of infertility are occurring in female patients (Shalom). These examinations are commonly practiced on patients who have had previous tubal ligation for investigation of the success of an attempted reversal, often following a pelvic ultrasound first (Mayer). After a speculum opens the vagina, non-ionic contrast is injected into a tube that extends through. This shows the structure of the uterus and function of the fallopian tubes (Shalom). The hysterosalpingography is extremely accurate in the evaluation of the female reproductive system, more so than any other function examination. This examination shows any infertility issues that are the result from structural and developmental abnormalities (Mayer). For this reason, it is important for radiologists to be familiar with these examinations. Often times having this examination helps to open the patient's fallopian tubes and allows the tubes to be more patent for oocytes to travel, resulting in pregnancy. If a patient is currently pregnant or has an active pelvic infection, they should not undergo a hysterosalpingogram (Mayer). Images of early uterus filling, complete filling, the fallopian tubes, and any peritoneal spills should be acquired.

Fluoroscopic image showing spillage of contrast bilaterally from the Fallopian tubes (Shalom, figure 8, p.1)

Urinary Fluoroscopy

There are several fluoroscopic examinations that are performed of the urinary system that check the structure and function of the bladder and kidneys. A retrograde urethrocystogram is executed when there is a possible fistula between the bladder and rectum (Shalom). This often occurs due to post-operative complications. To perform this examination, contrast is injected into a catheter until the bladder reaches a specified level of fullness. Voiding cystourethrograms are used when patients are having reoccurring urinary tract infections (Shalom). This examination is mostly performed on adolescent patients. Radiologists focus more on the function of the kidneys and bladder in effort to rule out urinary reflux that could lead to concurrent UTIs (Shalom). For this examination, a catheter is inserted into the bladder and filled with contrast until the contrast has reached the kidneys. This examination could be traumatizing for children due to the pain that accompanies having a catheter inserted into the urethra. Intravenous pyelogram (IVP) is another examination that observes the structure of the kidneys and bladder. IVPs are routinely performed when a patient has a history of kidney stones to ensure that there is no obstructive stone from the ureters to the bladder. The IVP is performed differently from other fluoroscopy examinations of the urinary system. For an IVP the patient receives an IV for contrast injection. After the contrast is administered, either tomographic images or x-ray images are taken in specified time frames until both kidneys and the bladder are opaque.

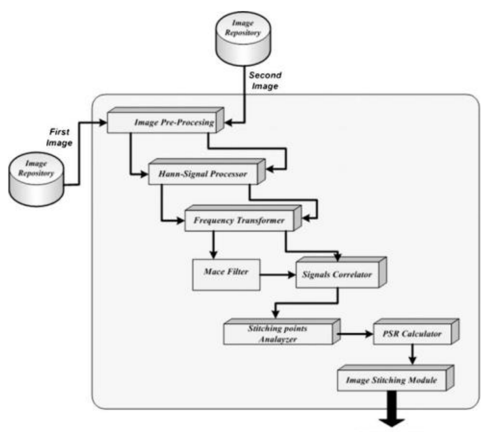


Fluoroscopic image of right kidney, right ureter, and bladder post contrast administration

(Shalom, figure 10, p.1)

Automatic Stitching Software

Conventional equipment in radiology has a limited field of view (Samsudin). When the physician orders a radiologic image of the long bones or spine, the entire anatomic structure will not fit on one image. With image stitching, two radiographs that are overlapping can be merged together into one image (Samsudin). The software system identifies areas of the image that are the same and automatically aligns the image. In some cases, the radiographer may still need to adjust the anatomy to achieve an accurate radiograph by moving one of the overlapped images up or down and left or right. The first step of automatic stitching is preprocessing the image. A histogram is employed to adjust the brightness of the original image and helps redistribute the intensities throughout the image (Samsudin). Next, the frequency domain transformation calculates real-time domain values into frequency domain values and stores the results. After that the image filter computer executes the minimum average correlation energy (MACE) filter to take all the input images and minimize the standard correlation energy and improve the sharpness of the image (Samsudin). The next step is performed by the correlation filter module. In this step, the module performs cross-correlation between the two images to search for the similarities between them. After that, the time domain transformation occurs in which the inverse in time transformation is found, followed by the peak value (Samsudin). Once the value of the similarities between the images are computed, the location of the highest peak is used in the next step. The peak to side ratio is used for the correlation filter to ensure the image is overlapping and not being tricked by non-dominant local peaks. Finally, the image stitching module registers and blends the image by locating the peak of the correlation plane to create a panoramic image (Samsudin).



Steps of the Image Stitching Method (Samsudin, figure 1, p. 1)

Long Bone and Spine Stitching

Automatic stitching is often used in digital radiology when radiographing lower legs for long-bone measurements and when taking images of the spine for scoliosis (Yang). These images help for surgical mapping of bone malformations. In order to diagnose scoliosis, images are taken in an anterior-posterior position from the skull on down to the bottom of the coccyx. If there is any curvature laterally, the patient has scoliosis. Scoliosis can often be debilitating, and medical assistance is required. Depending on the severity of the scoliosis, the patient may require surgical intervention. For long bone measurements, images are taken from the femoral heads on down to the ankles. These are also done in an anterior-posterior position and include both legs. This imaging technique is used to determine inequality in the length of the legs. These images help in surgical planning of implant size to eliminate these discrepancies.

Future Radiologic Innovations

Technology is still constantly on the rise, so it is no surprise that researchers are working on several groundbreaking discoveries for the radiology use (ScienceDaily). Three different research departments, the University of Maryland, Baltimore County (UMBC), and University of Baltimore are currently testing an advance for computed tomography images. These facilities are testing protocols that use color to identify microfractures in the bones (ScienceDaily). If microfractures are nondisplaced, they are often impossible to see on plain film radiographs. To use this new technology, technologist expose the patient to the particle hafnium, which the body can safely excrete. These particles become attached to the microfractures and are there during the imaging process (ScienceDaily). X-rays are able to detect hafnium because of its chemical composition and the result is images that have color deposited in the fracture sites.

Another development being studied is the use of artificial intelligence to instantly detect strokes in computed tomography scans of the head (Alexander). If a stroke is flagged, the examination is moved to the top of the radiologist's reading list. This promotes prompt treatment for the patient, leading to increased likelihood of recovery with fewer lasting symptoms. There is also research being conducted that make patient images more accessible (Alexander). Cloud-Based storage, a lot like iCloud, are seeming to be easier for patients to access their images as well as cheaper and more secure than modern storage systems. This invention would also aid in transferring medical records to facilities and physicians that request this information. Blockchain can help prevent data breaches that occur in health care (Alexander). If ever a breach is detected, the system can maintain functioning, unlike other systems which end up locked down.

Lessons Learned

Since its first discovery, radiology has been introduced to many new innovations. Screen film radiology was a lengthy process that require the technologists to run film in a developer. This was a lengthy and sometimes tricky method. Digital radiology was one of the first major milestones in the invention of radiology. The ability to instantly see the radiograph after exposure was astronomic to the screen film world. Being able to quickly see these images has definitely saved lives of critical and trauma patients. Patients that required a chest tube for a collapsed lung or emergent surgery for lodged foreign bodies that were swallow rely on the quick capture and review of these patients (O'Connor). Digital images also have good software reprocessing systems so the image can be made to look prettier once it has been corrected. The PACS system has made storage of radiographs much easier than using a film jacket. Now less waste is produced by film and paper. This way of storage also frees up space for the facility. HIPAA is protected by lost, misfiled, or stolen radiographs, making the patient's information more secure (Strickland). Another great addition PACS offers is the ability to quickly share images with other facilities. Power Shared images can be pushed within minutes. This may have resulted in the loss of jobs for the file room employees because after a decade of switching to digital images, all files were destroyed. PACS also makes radiologists reading paper free and increases their ability to work remotely. The radiologist no longer has to read film and write his impression down. Now the images populate on the computer and the report is typed as the radiologists speaks it into the microphone. Automatic Exposure Chambers benefits the patient more than anyone else. These chambers are responsible for determining how much radiation is required to adequately expose a patient, pending the positioning is correct (Sterling). There are three chambers, one in the bottom center and two at the top, one on each side. If the correct body part is over the correct chamber, the system terminates after a set amount of radiation reaches the area. The higher the atomic number of the body part being imaged, the higher the radiation dose. Anything with calcium will require more radiation than soft tissue images. Also, the thicker the body part, for instance your femur compared to your humerus, the more radiation will be required to penetrate the area. This is beneficial to patients because they no longer have technologists guessing at how much exposure will be required, often leading to repeats if the factors they enter are incorrect, thus resulting in less radiation exposure. However, if the body part is positioned wrong, the automatic chamber will receive the incorrect amount of radiation filter through, resulting in incorrect exposure. Repeated exposure to radiation can lead to cancers forming from DNA change (Newman). Although rare, there are studies that predict 0.4 percent of cancers coming from computed tomography scans due to the over-utilization by providers today (Majeed). There are also acute side effects like erythema, fatigue, loss of appetite, nausea, vomiting, and headaches that can come from large dosage exposure. Long term effects could include ischemic heart disease, chronic diarrhea, and ulcers of the gastrointestinal system. Portable radiology paved the way for patients who are unable to move very well. Technologists are able to bring the x-ray equipment to the patient for examinations. This was especially important for immune compromised patients during a brand new, air-borne spread illness like COVID-19. Containing the sick patient in their rooms helped patients and visitors around them from being exposed and contracting the illness themselves (Zubair). Digital portable radiology has come about in recent years and drastically changed radiology procedures. Now images instantly populated on the screen after exposure and the technologist and patient are spare tremendous time but this occurring. Before you would have to run the plate and hope your positioning was correct the first time or you would have to travel back to repeat it. Lead barriers were created to contain the amount of radiation exposure to radiologic employees. Walls are made with lead that is 20 – 23 centimeters thick to absorb scatter radiation and prevent workers from receiving more than the recommended occupational dose (Lakhwani). Radiologic technologists are also trained to distance themselves and spend as little time as possible directly in the beam of radiation, (OSHA). The more distance you can get between you and the intensifier, the less scatter radiation your body will absorb. The recommended distance for anyone not being radiographed is six feet. There are lead shields to wear when distance and time are not an option (Lakhwani). Lead is chosen to compose these shields due to its high atomic number and ability to stop gamma rays and x-rays. The most important area to shield is gonads, especially during the younger, childbearing years. The thyroid is also important to shield due to its sensitivity to radiation exposure. There are lead aprons made for occupational used that cover the breast, abdomen, pelvis, and mid femur if fitted correctly. There are also the options for lead glasses to help prevent cataracts and lead gloves for workers whose hands are constantly under the x-ray beam (OSHA). These are sometime worn by pain management physicians when they perform steroid injections under fluoroscopy. It is important to maintain the lead aprons as bends and holes can make them ineffective. Storage should be upright and on a hanger. Dosimeters are worn by employees to measure the amount of occupational radiation exposure received (University of Pittsburg). Most are worn at the collar, as the thyroid is a very sensitive organ and should be observed closely but the monitor measures fully body dose. There are also ring dosimeters that are worn by technologists who handle radioactive materials with their hands. These monitors are mainly worn by nuclear medicine technologists. Pregnant women wear fetal monitors at their waist to keep check on the fetus' exposure. If the pregnant employee wears a lead apron, this monitor should go below the apron, still at the waist, to ensure an accurate report. Most monitors are changed monthly, but some types can be worn for three-month periods and twelve-month periods. If a technologist receives 5 rems in a calendar year, which is the maximum allowable yearly dose, they will be required to take the remainder of the year off (Park). Portable computed tomography machines are fairly new but are a great addition to healthcare. For this reason, they are still limited in their abilities, but they can provide head images as well as some types of full body scans (Rumboldt). The reconstruction software is not as great as stationary machines, but STAT examinations can be done in the comfort of the patient's room. This increases the result time of CT scans allowing for quicker treatment of the assumed condition. It is important that technologist practice time, distance, and shielding when performing all portable CT examinations as they radiate more scatter exposure than traditional x-rays (Zubair). Mobile radiology has been shown to help with patient exposure due to its blatant decrease in repetitive exposures that would come from patient motion. When the exam is done in the comfort of the patient's rooms, they respond better to being cooperative. Mobile radiographs are done in the solace of a patient's residence. The portable x-ray machine is brought to their house or to the nursing facility, reducing stressful trips for confused patients and well as possible exposure to any deathly illnesses. People with lower functioning immune systems should lessen the likelihood of coming in contact with infections like COVID-19 or influenza. Additionally, patients are more satisfied with mobile radiology than they are with traveling to facilities and remaining in the waiting area until the examination can be performed. Another plus is the price of the in-facility and mobile radiology are very similar, so cost isn't an issue. Artificial intelligence systems are gaining popularity in radiology. The systems are able to indicate if there is an illness and more importantly, the type of illness present. Algorithms point out concerning areas for radiologist to review, the order depending on severity (Hosny). This could increase the response time of the patient's treatment. When a facility has artificial intelligence, the radiologist's workload is lightened because these algorithms can find concerning areas faster than the naked eye (GE). Examinations are then prioritized based on how critical the system has determined it to be. The artificial intelligence systems can also orientate images that radiographers flipped wrong or forgot to flip before the examination makes it to the reading radiologist. This saves the technologists from having to delete the incorrect images and resend the corrected one. There are also systems that will notify the technologist if the exposure is insufficient and in need of a repeat image. The MRI modality will greatly benefit from artificial intelligence systems because the algorithm can assist in aligning the body part and identifying the area of interest (Honsy). By doing so, the scan is uniform, and the smart technology helps to decrease scan time. A shorter scan time is important for patients who suffer from claustrophobia. There are two artificial intelligence methods, the first involves models that classify patients in order to assist in clinical decisions. The second is deep learning, which involves the artificial intelligence identifying abnormalities without previous indication from radiologists. This one is becoming the more popular choice. Artificial intelligence systems are more able to assist in identifying abnormalities in PET scans than radiologists are. The system is sensitive in quickly pointing out areas of concern and alerting the appropriate parties (Honsy). Maximum intensity projection is used in computed tomography to create enhanced images after contrast administration for angiography scans (Prokop). These images are created using areas that are much higher in contrast than the areas surrounding it. These types of images are mostly used in the arterial phase to look at large vessels for injury or occlusion (Rybicki). Due to the direction of blood flow of the heart, if the scan is timed correctly, the arteries will be the only areas opacified, which is important for the algorithms of MIP reprojections. The software will use the axial image volume since they are cut in very thin slices. Computed tomography angiography is one of the exams used by the MIP reconstructions. These scans require quick contrast administration in order to sufficiently opacify the artery for diagnostic large vessel review (Radiology Info). Successful completion of a CTA could prevent the patient from having to obtain hearth catheterization, as well as revealing occlusions and clots in the arteries, so sufficient scans are important. These exams could result in spending less money on testing, as well as quicker recovery if they are able to prevent being sedated for invasive examinations. Three-dimensional reconstructions are a result of reconfigured axial images that are used to create a three-dimensional image of the area of interest (Ram). These are used a lot in CTA exams as well. When scanning the arteries of the neck, software is used to create an enhance image for radiologist review. However, these exams are contradictive for patients who are larger and/or who have weak veins that will not uphold to quick contrast injection. Three-dimensional reconstruction is also used for surgical mapping, especially in joint replacements. These images help surgeons determine the size of the artificial implant as well as the best route. Axial images from the computed tomography scan are stacked on top of one another to create the three-dimensional look. If the joint that is being examined has had previous replacement, there could be issues with streaking from the prothesis, limiting the three-dimensional ability. Ultrasound also creates three-dimensional images, mainly in fetal examinations. These exams can help identify cleft lip as well as rib and spine abnormalities (Huang). Cardiac three-dimensional scanning creates images for measuring features, identifying anatomy, and separating tissues from each other (Greenleaf). These images allow for optimal views of the atrial septum and ventricular chamber. These images are often used in surgical mapping as well. The addition of electronic order helped reduce confusion about what the physician wants in regard to imaging (Pevnick). Paper orders were sometimes ripped, lost, or illegible. Having orders on the computer eliminated all of those issues. Any questions about the order could be solved with a phone call. Also, if there were issues with the order instead of waiting on a new order to arrive via fax, these could be corrected on the computer at a much faster rate. Paper orders should be double checked to make sure the correct exam is ordered according to the patient's symptoms as well as put on the schedule correctly. Any discrepancies should be pointed out for correction. C-arms are used during operations for assistance to the surgeon. There are many surgeons who use the c-arm but the most often use comes from orthopedics. This is especially true when they have to reduce a fracture before implanting hardware to hold the bone in the correct position. C-arm radiation comes from the bottom of the "c", so it is important to remember that in regard to how to shield yourself as well as the patient. Like portable machines, there is no wall to prevent you from scatter radiation exposure when using a c-arm so wearing lead shields are extremely important (Joh). Fluoroscopy is done when several images are shot within milliseconds of one another. This type of imaging is done in the radiology department with a radiologist in the room. There are several exams from swallowing studies to joint injections (Shalom). These exams are important to perform due to the benefit of being able to move and position the patient as needed throughout the entire exam. Fluoroscopy is not utilized as much as it used to be due to the radiology departments not stressing the importance of these exams. Also, new hire radiologists want to work remotely from home due to convenience. Most physicians order cross-sectional imaging due to the availability of same day examinations as well as patient preference. Another reason these exams are not performed as much as in the past is radiologist do not receive as much reimbursement doing a fluoroscopy exam as they would if they read an MRI or CT. Automatic stitching software help to create one image made from several radiographic exposures. For scoliosis, three images are taken, one for each part of the spine (cervical, thoracic, and lumbar), then the algorithm finds similarities in the overlapping images and creates a single long image of the spine (Yang). These are useful for surgical mappings and are mainly perform on adolescent patients. Long bone image stitching is done to examine inequalities of the lower extremities. Images are taken from mid pelvis to past both ankles in order to determine if the lengths of the legs are equal bilaterally. These are great mapping images to determine a surgery plan should intervention be required.

Conclusion

Since 1895 when Wilhelm Roentgen made that first discovery, there have been many changes to the entire radiology network. The report of his finding caused a great flood of desire to obtain knowledge from the scientists of that time. Though some can argue, I would venture to say all these changes brought about major benefits for the patient outcome as well as how health care is provided. Today, images can be exposed and seen within seconds. AI systems can flag critical results for immediate radiologist review. Patients have much better access to medical care today than they did even a decade ago. New technologies are constantly coming about in attempt to create a smoother radiology process. Patients even have the ability to review their imaging report online through many health facilities. This is something that I utilize heavily when I am a patient.

In order to work in radiology, you must be resilient and flexible. Change is inevitable with the constant release of the next big innovation. When these are introduced to the radiology team, you must be able to adapt and learn the new technologies. They are purchased to help the patient receive the best care possible. A lot of these inventions are there to help make your job easier as well, so you might as well welcome the change.

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