

APPENDIX A: RADIOGRAPHIC PRINCIPLES

(Radiographic Anatomy Packet folder: Radiographic Principles, images 01 – 10)

X-ray properties, radiographic density

Conventional X-ray studies, such as chest X-rays (CXR) or an X-ray of the hand, as well as computed tomography (CT) all use X-ray radiation. X-rays are similar to light in that both are forms of energy that propagate as waves. They differ in that X-rays have much shorter wavelengths that are capable of penetrating many substances that light waves cannot. You are *not* required to know the physics of X-ray energy or how X-ray beams interact with a screen to produce the ‘film’ image for the purposes of your Human Anatomy course (INMD 6150). However it is important that you familiarize yourself with the types of tissues that differentially absorb or scatter X-rays because it is your job as students of anatomy to know all anatomical relations in your cadaver *and* how selected relations can be identified radiologically.

The ability to distinguish a rib from the heart and to identify lung borders on a CXR exemplifies the two basic properties of X-rays as they interact with matter: absorption and scatter. As a general rule, the degree to which a given media absorbs or scatters X-rays is a function of its density. There are five basic radiographic densities that are important: air, fat, soft-tissue & water, bone, and metal & contrast agents.

Open up image **RGP.01** in your Radiographic Anatomy Packet under the file name “**Radiographic Principles**” as a reference to this discussion. This diagram displays the radiographic spectrum range from “white” to “black.” When X-rays travel through extremely low-density media such as air (e.g., lung or bowel gas) they are very weakly absorbed, allowing nearly all of the X-ray’s energy to “blacken” the film. Conversely, at the opposite end of the spectrum, when X-rays impinge upon very dense metals (e.g., steel in a prosthetic limb) they are entirely scattered and a shadow is cast on the film that appears “white.” In between these two extremes are mixed degrees of absorption and scatter. For instance, bone (composed of high molecular weight calcium) and barium contrast (a dense liquid) appear predominately “white” depending on their thickness (thin rib bones scatter less than a thick vertebral body), or concentration (diluted barium will appear more “gray” than a pool of concentrated barium). In radiology, contrast agents are routinely utilized to accentuate anatomical structures of interest (as you will see below). In fact, more than half the images in your Radiographic Packet involve the use of contrast agents, (given intravenously to display vascular structures, or given orally to study the alimentary tract). As you begin learning anatomical radiology in your Packet, use **RGP.01** and some of the other images in the “**Radiographic Principles**” file as a reference.

You have already seen how tissues that vary in density influence the X-ray image. When X-rays pass through low-density media like air, more X-rays will reach the film that corresponds to this tissue than a nearby area where the X-rays encounter the heart, which will both absorb and scatter X-rays to some degree resulting in a “grayer” film exposure. It is the *amount* of X-rays that hit the film over a given period of time to produce an image representative of whatever object lies in it’s path. If the amount of X-ray exposure is increased by prolonging the period of time (or by increasing the beam intensity) then more X-rays will reach *all* areas of the film. As you might have guessed, when film is “overexposed” the end result is a “darker” image (see the ‘spectrum’ on the

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bottom of **RGP.01**). In radiology, the amount of X-ray exposure for each region of the body can be pre-selected based on “presumed structures” within the area of interest. For example, less exposure is needed for a CXR because most of the chest’s volume is air-filled lung which absorbs very little X-rays resulting in film that is “blacker.” In contrast, more exposure is required for an abdominal X-ray because structures in this region (intestine, solid organs, and retroperitoneal muscle) all absorb and scatter X-rays resulting in fewer X-rays reaching the film and an image that is “grayer,” (see ‘spectrum’ on bottom of **RPG.01**).

X-ray exposure can also be individualized for each patient. For example, an abdominal X-ray of an obese patient requires greater exposure because X-rays will encounter larger volumes of tissue than a similar study performed on a small patient.

X-ray properties, divergence

Conventional X-ray of any kind consists of a device that emits X-rays that *diverge* (spread out) from their origin. These beams are in turn differentially absorbed or scattered by objects within their path and ultimately terminate by exposing a film. The property of divergence is best explained by example as shown in **RGP.02**. When an object (blue upright arrow) is placed between a hypothetical source of energy (e.g., the yellow sun) and a film, the image cast by the object’s shadow differs according to the distance between the object and the film. The object in both pictures is identical (30” X 10”), but the distance between the object and the film changes from 1 foot (above cartoon) to 5 feet (bottom cartoon). This results in relative (1) “*magnification*,” and (2) “*blurriness*” of the image. You can demonstrate this to yourself by placing your hand about 5 inches from this page and moving it away from the page; again, not only is the image (shadow) “magnified” but it is also “blurred” the farther your hand moves away from the page. To minimize such an effect, radiologists attempt to position the patient whenever possible. Thus, *its distance from the film influences an object’s projected image*.

Chest X-ray (CXR)

The chest X-ray (CXR) is one of the most frequently ordered radiographic tests in medicine for several reasons. It is easy to perform, cheap, rapid, involves little or no patient discomfort, and exposes the patient to almost negligible amounts of radiation. Because sufficient fundamental information about cardiopulmonary (heart & lungs) systems can be obtained from the CXR, it is commonly the first radiographic test performed when illness/involvement of these vital organs is suspected. As you will learn in your clinical years, decisions are frequently made from the initial CXR.

By convention, clinicians always evaluate every CXR as though they are facing the front of the patient, just like a photograph. Hence, the CXR is placed on the viewing box such that the right-hand side of the CXR is the patient’s left side, and the left-hand side of the CXR is the patient’s right side. In human anatomy, you should begin to familiarize yourself with some of the important CXR landmarks and part of this begins with understanding the different ways in which a CXR is obtained. For our purposes,

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the three views that you should know are: Posterior-Anterior (PA), Anterior-Posterior (AP), and Lateral.

Performing a Posterior-Anterior Chest X-ray (PA-CXR)

In radiology, the study is named according to the direction the X-ray beam passes through the patient. The Posterior-Anterior chest X-ray (PA-CXR) is so named because the X-ray beam passes through the patient's back (posterior) and exits through the front (anterior) of the patient to expose a film placed against the patient's chest. Remember that *an object's projected image is influenced by its distance to the film because X-rays diverge*. As shown in the side-view and bottom-up (axial cross-section) view cartoons in **RGP.03**, the magenta X-ray beams diverge from the source, passing through the patient's back (and posterior structures such as the vertebral column), traversing through lung and the more anteriorly positioned heart, and terminating on the film that lies anterior to the patient. Because the patient's heart is positioned closer to the film than posterior structures (such as a vertebral body), the projected image of the heart is less magnified. This is why the PA-CXR is the preferred method for obtaining a CXR *when the patient is able to tolerate an upright position*.

Performing an Anterior-Posterior Chest X-ray (AP-CXR)

As the name implies, an Anterior-Posterior Chest X-ray (AP-CXR) is done with the patient's back closest to the film and the X-rays pass from anterior (front) to posterior (back) to expose the posteriorly placed film (**RPG.04**). In contrast to the PA-CXR the AP-CXR results in magnification and blurring of anterior structures such as the heart, (compare **RPG.04** with **RPG.03**). To see the difference between a PA-CXR and an AP-CXR look at **RGP.05**, which shows the two studies side by side.

It is important to remember that when clinicians evaluate any CXR, *regardless of whether it is a PA-CXR or an AP-CXR*, it is always placed on a viewing box as though you are facing the *front* of the patient, as described above.

Clinical correlation:

Distinguishing between a PA- and an AP-CXR is clinically important for several reasons. As a general rule, *assuming that the patient can stand upright without difficulty*, the PA-CXR is the study of choice and is typically accompanied with a lateral CXR, both of which are obtained with the patient in the *upright* position (**RGP.03**). PA-CXR's have been standardized, meaning that the distance between the X-ray source and the film is 6 feet, a 'phototimer' is utilized to ensure that the time of exposure is optimized to the patient, and the patient is accurately positioned.

In some patients, it is not possible to obtain the more preferred views because the patient may be too sick to be transported to the radiology department for an upright PA- and lateral CXR. For an AP-CXR (also called a "Portable CXR," because a portable X-ray unit is wheeled into the patient's hospital room), the film is slid under the

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patient's back and the source is positioned above the patient at a distance that is variable, (typically 3-4 feet). In addition, because technologists cannot always optimize positioning or control the patient's rate of breathing, the AP-CXR has a more limited role as a diagnostic test. Furthermore, the inability to stand upward (e.g., an ill patient in the intensive care unit, ICU) also prevents one from obtaining a lateral CXR (explained below). Despite these pitfalls, the AP-CXR is still useful for observing the proper placement of several life-saving devices: chest tubes, intravenous (IV) & intraarterial catheters, endotracheal tubes (ventilator), pacemaker leads, and to detect problems that may be associated with these devices (e.g., pneumothorax). In most ICU patients, a daily AP-CXR is obtained to evaluate the patient's progress (e.g., resolution or worsening of pulmonary edema or pneumonia) and to evaluate the devices mentioned above. Again, look at **RGP.05** to see the PA-CXR and the AP-CXR ('portable CXR') side by side.

Lateral CXR

Conventional X-ray studies are limited in their ability to transform information about a 3-dimensional object (human body) into a 2-dimensional image of that object. The resulting superimposition of two or more overlapping structures creates what is known as a 'shadow,' that may obstruct a structure of interest. This problem can be partially resolved when two views of an area are obtained from a different perspective. In a PA-CXR for example, significant posterior portions of the lower lung lobes are 'hidden' by the heart and diaphragm. However on a lateral CXR these same areas are easily seen (see **THX.CXRP.2** and **THX.CXRL.1**, found in the 'thorax' [THX] radiograph folder). Therefore when a patient is able to tolerate upright positioning, PA- and lateral views are considered necessary for a good X-ray evaluation of the chest. The rationale of obtaining two different X-ray views is so important that every part of the body is imaged in 'more than one view' to minimize overlap of soft tissue or bony structures whenever possible. This is especially true in the orthopedist's quest to evaluate for – and plan their surgical approach to – bony fractures.

Performing Computed Tomography (CT)

Computed tomography (CT, also known as a 'CAT-scan') has greatly enhanced the radiologist's ability to visualize anatomical structures. Because CT uses X-rays, the principles that apply to conventional X-ray also apply to CT. In CT, X-rays are released from a source and diffuse outward where they are absorbed or scattered by objects (human tissue), and ultimately expose a receptor to produce an image. CT differs in the manner in which the image is obtained (**RGP.06**). As shown by the cartoon to the left in **RGP.06**, the patient lies in the supine position (on a thin platform called a "couch," not shown) and is moved either forward or backward through a large 'doughnut-shaped' structure. The 'doughnut' houses both the X-ray source and receptors. As shown in the cartoon on the right, small volumes of the patient (in this case the thorax) are exposed to X-rays emanating from a source that rapidly rotates 360⁰ around the patient. The entire thorax can be scanned from top to bottom in a few seconds making it possible to complete a study in a single breath hold.

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CT studies are most commonly displayed as *axial* images that tend to confuse beginning students for two reasons. Firstly because most of the 'lay' population assumes (by convention) that any reference to the human body will be in the upright/standing posture (where we spend most of our waking lives) just as other objects, such as houses are conventionally thought of in their normal upright position. And secondly because most of the 'lay' population is more familiar with thinking of cross-sections in a plane that is parallel to the ground as being viewed from the 'top-down' (e.g., like floor plans for a home). However, axial CT images are performed with the patient lying supine and are displayed as if looking from the 'bottom-up.' To make sure that you always remember this, approach each axial CT image with two things in mind: (1) the patient is lying supine (on their back, just like your cadaver lies in your lab table). And, (2) look at each image as though you are positioned at the patient's feet, viewing superiorly or toward the patient's head. If you do this, you will never forget that the right hand side of the patient is always on the left of the image, just as it is when viewing a CXR.

CT images can be displayed in different formats called 'windows,' to facilitate evaluation of tissues within a region of interest. For example, in the thorax folder of your Packet there are axial CT chest images displayed in "Soft-tissue Windows" and "Lung Windows." Radiologists use Soft-tissue Windows to evaluate muscle, blood vessels and solid organs, whereas Lung Windows accentuate the fine detail of the lung tissue. A third format, called "Bone Windows" is used to evaluate bony structures such as the paranasal sinuses in the skull (see **H&N.CTCO.1-3** in the 'Head & Neck' folder).

Although most radiologists prefer to evaluate CT images in the axial plane, newer machines are capable of reconstructing coronal, sagittal, and even 3-dimensional images. These views are becoming more popular to visualize anatomical relationships in a different perspective and examples of each are included in your Radiographic Packet.

Use of contrast agents

Contrast agents are commonly employed in radiology to accentuate hollow or tubular anatomical structures of interest. Such studies are called "contrast enhanced." The two most common routes of contrast administration are (1) oral or rectal, for studying the anatomy of the gastrointestinal tract, and (2) intravenously (IV), to study the cardiovascular and/or urinary systems. Your Radiographic Anatomy Packet has several examples of each. The following is a primer that you may find useful when approaching contrast enhanced radiographs.

Oral and rectal contrast agents (e.g., barium) are high molecular weight compounds that are neither digested nor absorbed within the gut, making them ideal for observing the anatomy from the pharynx to the anus. Oral agents are used to image the anatomy of the esophagus (see **THX.XRAP.1** in 'thorax' folder), as well as the stomach and small bowel (see **ABP.XRAB.5** in 'abdomen & pelvis' folder). In this study, also known as a 'Barium esophagram,' it is possible to observe the dynamics involved in the process of swallowing by using fluoroscopic real-time video to capture each phase as a bolus of barium goes 'down the hatch.' Later, the video can be played

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back in slow motion to identify abnormalities. To study the entire digestive tract, radiologists will ‘follow’ the progression of barium as it winds its way through each loop of bowel, a process called an “Upper GI” (UGI) study.

When imaging the colon, barium is administered per rectum (usually with air insufflation) in what is called an “Air-Contrast Barium Enema” (ACBE). In this way the barium will coat the walls of the colon and because air serves to expand the bowel lumen, fine topographical detail of the mucosal surface can be observed (check out images **ABP.XRAB.7-10**). Under normal circumstances, when pressurized barium is given per rectum it will coat the entire colon without reflux into the small bowel because the ileo-cecal valve (a relatively strong sphincter muscle) is closed.

The vascular and urinary systems are studied using contrast agents that are administered intravenously (IV) and require a basic understanding of vascular physiology, which you will be exposed to in anatomy. Peripheral veins (like those in an arm or a leg) bring oxygen-depleted blood back to the right side of the heart where blood is pumped through the pulmonary arteries to the lungs to be oxygenated. Oxygen-rich blood then returns to the left side of the heart and is distributed throughout the body via arteries. Arterial branches that are close in proximity to the heart/aorta (so called ‘proximal branches’) such as the renal arteries, will receive blood sooner than those that are farther from the heart/aorta (‘distal branches’) such as capillaries in the foot.

To perform an IV contrast study, a diluted solution of contrast is injected into a peripheral vein (typically the easily accessible medial cubital vein) and imaging is begun shortly thereafter depending on the region of interest. Once contrast is injected, veins carry it to the right side of the heart, mixing with blood that has returned from the head & upper extremities via the superior vena cava, (SVC) and from the rest of the body via the inferior vena cava (IVC). From here the contrast/blood enters the pulmonary system and returns to the left side of the heart where it is distributed to all parts of the body via the arterial system.

Thus, when contrast is injected into a peripheral arm vein, it takes time for the contrast to become equally distributed throughout all vessels. As shown in **RGP.07** contrast is seen within the abdominal aorta, the right kidney, and the renal veins that drain from the kidneys. This coronal view was captured just as contrast (white) was beginning to empty from the renal veins into the IVC. Blood in the IVC is not yet opacified because contrast has not yet returned from the lower extremities at the time of image acquisition. If time was extended for a few more seconds and images were then taken, all of the vascular structures would be opacified.

For reinforcement of this concept, look at **RGP.08**. This slide shows four axial CT images (**A – D**) that were acquired serially such that image **A** is an ‘early’ image taken 30 seconds after IV contrast administration (into an arm vein), and image **D** is a ‘late’ image taken at approximately 8-10 minutes. The purpose of this teaching slide is for you to observe how the vascular system distributes IV contrast according to the properties of vascular physiology with respect to time, which is best exemplified in the renal system. In each of the four axial images, pay attention to the three numbered labels (**1** is the **IVC**, **2** is the **Abdominal aorta**, and **3** is the **Kidney**). At 30 seconds

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after IV contrast injection (image **A**), the abdominal aorta and kidney cortex are opacified, while the IVC is non-opacified. At 1-2 minutes (images **B** and **C**), contrast has entered the kidney cortex and medulla as well as the IVC (because enough time has passed such that contrast-filled blood has entered and subsequently returned from the lower extremities). In image **D**, contrast has been completely cleared out of the vascular system (abdominal aorta and IVC). Low levels of contrast are seen in the kidney cortex & medulla and bright contrast-filled urine can be seen in the renal pelvises/ureters because it has entered the urinary collection system.

Radiologists take advantage of IV contrast enhancement to accentuate not only blood vessels but to evaluate several organs because each organ has a characteristic vascular pattern when enhanced by contrast (see **RGP.09**). Organs with a rich vascular supply will greatly opacify with contrast and appear 'whiter' than surrounding structures. Examples of highly vascular organs are: thyroid and kidney cortex (**RPG.09** and compare to **RGP.08** kidney cortex). You can see that these two organs look almost as 'white' as nearby blood vessels. By comparison, tissues that are less vascularized will be unchanged by the presence of contrast. Examples of less vascularized tissues are fat and muscle. In-between these two extremes are tissues/organs that receive an 'intermediate' blood supply. For example, the spleen as shown in **RPG.07** and **RPG.09** is more vascularized (and whiter) than liver, but is less vascularized (and 'grayer') than kidney or nearby blood vessels. Look at these two examples (**RGP.07** and **RGP.09**) with more scrutiny and try to convince yourself of the following in decreasing order of contrast enhancement (from greatest to least): vessels > thyroid & kidney > spleen > liver > muscle > urinary bladder > fat > air. These same relations have been summarized on the 'radiographic spectrum' in **RGP.01**.

Radiologists can image the urinary system in one of two ways. To evaluate the kidneys, ureters and bladder, IV contrast is given and because the kidneys' function is to filter blood, any filtered contrast will pass into the renal pelvis (as explained above) and subsequently more distal structures such as the ureters and bladder. This type of study is called an Intravenous Pyelogram (IVP) and is performed in the following stepwise manner. First, *before* IV contrast is given, an AP-X-ray of the abdomen (a.k.a. a Kidney-Ureter-Bladder, or KUB) is taken to evaluate for abnormalities such as kidney stones, (see **ABP.XRAK.1-2** in the 'Abdomen & Pelvis' folder). Next a series of 3 or 4 AP-abdominal X-rays are taken at 5, 10 and 20 minutes *after* IV contrast administration. The earliest film (5 minute) will opacify the kidney cortex, whereas subsequent films will opacify distal structures (ureters and bladder). Typically at the end of the study, the patient is instructed to void and a final film, called a 'post-void' is taken to evaluate bladder emptying. With minor modifications, this same type of study can be performed by CT. See **ABP.CTAG.3** and **4** (in the 'Abdomen & Pelvis' folder) for examples of 3-D image reconstruction using CT.

As shown in **ABP.XRAK.4**, (found in 'Abdomen & Pelvis' folder) an IVP can detect anomalies in the genitourinary (GU) system. As you will learn in embryology, more anomalies occur in the GU system (e.g., 'horseshoe kidney,' 'bifid renal pelvis' to name a few) than in *any* other organ system in the body.

As you become more familiar with structures that differentially enhance, use this knowledge to identify organs (*hints like this come in handy in the exam*). In your exams,

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you will be given an entirely *blank* radiograph (having only a title) with an arrow pointing to one structure. If you have familiarized yourself with “Radiographic Principles” and have reviewed all Packet radiographs by testing yourself as you go (switch back and forth between the ‘Lettered’ (L) and ‘Named’ (N) pair of radiographs) you will be well prepared!

Performing Abdominal Ultrasound

Radiologic ultrasound (US) has quickly established itself as a safe, useful diagnostic tool. This is especially true in obstetrics & gynecology where accurate fetal dating and assessment (without radiation exposure) has now become routine. At centers involved in organ transplant, Doppler US is regularly used to examine the patency (openness) of graft blood vessels. In addition, US is considered the test of choice in the diagnosis of gallbladder disease.

US uses a *transducer* that converts electrical energy into high-frequency sound energy (inaudible because it is beyond the threshold of human hearing) that is transmitted through human tissues. The same transducer also receives the ‘echoes’ of sound that are reflected from tissue. Received sound energy is then processed and displayed on a screen where images can be visualized in real-time, allowing for continuous feedback throughout the exam. The most common type of transducer used is called a ‘sector,’ which, like an X-ray source, sends out ultrasound waves that diverge (see **RGP.10**). In the cartoon to the left, the size of the transducer and placement on the patient’s abdomen is shown. A small amount of gel is first applied to the skin surface to reduce air interference, then the transducer is positioned over the contours of the patient’s skin. In performing an abdominal US, the transducer can be oriented in any plane including axial, sagittal or any oblique combination to visualize the region of interest. As shown in **RPG.10**, the US waves ‘fan-out’ in the sagittal view but appear as a ‘line’ in the axial view because this is the orientation of the transducer when used to obtain the resulting image seen in the right lower corner.

In US, certain tissues are capable of transmitting sound while others reflect. Air, bone, and highly dense material (e.g., gallstones) are highly *reflective* of sound and are called “hyperechoic.” This is why (with some exceptions) lung and structures within the skull (brain) are not normally studied with US. When US waves are reflected from dense objects like a gallbladder stone or a vertebral body, they leave what is called an “acoustic shadow” that appears as a black streak beyond their anticipated path, and obscuring more distal structures that lie beyond. In contrast, cystic (fluid filled) structures such as bile in the gallbladder (or urine in the urinary bladder) are “hypoechoic” or even “anechoic,” allowing nearly all waves to pass through them. As a consequence, structures that lie more distal to (or ‘behind’) an anechoic structure (such as the bladder) can be easily visualized (such as the uterus and ovaries). Other tissues such as muscle or the liver have “intermediate echogenicity.” As a final graduation from “Radiographic Principles,” study the sagittal and axial views in **RGP.10** and attempt to identify the structure in the corresponding US image (bottom right corner). Link to **ABP.USAB.3** to check your answer.