Radiation Therapy: Which type is right for me?

There are different types of radiation therapy that are commonly used today. Radiation therapy can be classified according to the various types of radiation particles or waves that are used to deliver the treatment, such as photons, electrons, or protons. Of these, photons and electrons are widely available and thus most often used. Protons are available at a number of institutions in the US and other countries, with new proton therapy facilities under development or in the planning stages. Generally, the three major subtypes of radiation therapy have similar biological effects on tumor tissue, meaning that they all have relatively similar potential to eradicate tumors; however, each type does have certain advantages and disadvantages, and we will briefly discuss the situations and rationale behind why your radiation oncologist may recommend one treatment modality over another. Your radiation oncologist is an expert at deciding which of these modalities is the best choice of radiation therapy in your particular circumstance.

Photon Treatment

Photons can be used in several different types of radiation therapy. This includes orthovoltage radiation therapy, conventional radiation therapy, 3D conformal radiation therapy, Intensity Modulated Radiation Therapy (IMRT), brachytherapy, volumetric modulated arc therapy (also known as RapidArc), and stereotactic radiation therapy, also known as radiosurgery, GammaKnife, CyberKnife, or SBRT. Photon beams are the same type of beam that are used in diagnostic X-ray machines, such as those used to take chest X-rays; however, in radiotherapy, much higher energy photon beams are used. Conventional radiation therapy, 3D conformal radiation therapy, and IMRT are generally all delivered by machines called linear accelerators, or "linacs" for short.

Two-Dimensional Photon Therapy ("Conventional" Radiation Therapy)

When 2D, or conventional radiation therapy is used, X-rays films are used to determine how best to position the radiation beams in order to adequately treat tumors. Typically, a machine called a fluoroscopic simulator is used to plan the radiation treatments. The bones seen on the X-ray are used as landmarks to determine where the tumor is and where to position the radiation beams around the patient in order to treat the tumor, but avoid normal organs. Planning can be done rapidly, and the patients can start treatment very quickly, as opposed to other techniques that require more in-depth (and time consuming) planning. This type of treatment is generally reserved for urgent treatments.

3D Conformal Radiation Therapy

With improvements in CT imaging quality and availability, the vast majority of hospitals are using CT (Cat scan-based) imaging to plan treatment for tumors in a process known as 3D conformal radiotherapy. The advantage of CT-guided therapy compared with conventional therapy is that CT-guided therapy allows the tumor and normal organs to be defined in three dimensions, as opposed to using the "flat" image of an x-ray. In this type of therapy, a CT or PET scan, often referred to as a "simulation", is obtained of the person in the position that they are to be treated. The tumor is then outlined in three dimensions on the CT scan. Normal organs that are located near the tumor and need to be avoided are also outlined in 3D (figure I, below). Beams are then arranged to best avoid normal organs, while delivering an optimal dose of radiation to the tumor. Computer software is then used to calculate the amount of radiation the tumor and normal tissues receive in order to assure that all parts of the tumor are covered sufficiently, while healthy organs receive as little radiation dose as possible. The beams of radiation can then be adjusted based on these calculations to further optimize the dose to the tumor and minimize the dose to normal organs. In addition to optimally positioning the beams, the radiation beam is shaped with one of two mechanisms, cerrobend blocks or multileaf collimators. Cerrobend blocks can be individually molded to the shape required or, in some linear accelerators, "leaves" within the machine can be used to form highly tailored beam shapes. Leaves (also known as multileaf collimators, or MLC's) are skinny metal blocks, which are able to move quickly and independently to form different, complex patterns (figure II,
below). MLC’s are now prevalent and readily available in most developed countries. These leaves are a critical component of IMRT, which we will discuss next.

**Intensity Modulated Radiation Therapy (IMRT)**

IMRT is another way to deliver the same photons to treat a tumor, but with the potential to lower the high doses of radiation that healthy structures receive. The process of planning IMRT also begins with a simulation. Similar to 3D conformal therapy, the tumor and normal organs are outlined on the CT with 3-dimensional information (figure III, below). Multiple beams are positioned at various points around the person to optimally deliver the radiation. However, in IMRT, these beams are divided into a grid-like pattern, separating the one big beam into numerous smaller "beamlets." Special software is used to determine the best pattern of beamlets to use from each larger beam, in order to deliver the optimal amount of radiation to the tumor while sparing normal organs as much as possible. To deliver these patterns, the MLC's form numerous different shapes, often 50 or more, during the course of a radiation treatment. The advantage of delivering radiation as beamlets to form these patterns is that very precise control of the radiation is obtained, which can be utilized when a tumor is in a difficult position to treat. For example, if a tumor is directly adjacent to a normal organ or wrapped around a normal organ, IMRT can shape the radiation such that it avoids as much of the normal organ as possible, but still delivers a large dose to the tumor (figure IV, below). This is why IMRT is commonly used in cancers of the head and neck where many critical structures, that may be near the tumor, such as the spinal cord, must be avoided. IMRT has become the most frequently used radiation modality.

The downsides of IMRT are that it can take longer to both plan the treatment course and deliver the daily treatment than 3D conformal therapy due to the numerous shapes the leaves are required to form. Also, because so many small beamlets are being used, the dose of radiation going to the tumor may not be as even as is usually seen with 3D conformal therapy. Furthermore, one of the disadvantages of using a greater number of beams to shape the radiation is that while normal organs are spared high doses of radiation, a larger volume of normal organs receive a low dose of radiation. The implications of the low dose exposure are unknown at this time. Finally, some tumors can move, for example, the lung moves with breathing, making treatment planning very challenging.

An additional type of IMRT that has developed in the past few years is known as Volumetric Modulated Arc Therapy (VMAT). It is very similar to IMRT except, in VMAT, the Linac rotates 360 degrees around the patient while simultaneously delivering the radiation, increasing the number of angles and decreasing the high dose radiation to normal tissues. One common type of VMAT is known as RapidArc. RapidArc has been employed in head and neck cancers, brain tumors, GI cancers, prostate cancers, and lung cancers.

**Image-Guided Radiotherapy (IGRT)**

During treatment with IGRT, imaging scans are repeated. The scans are processed by computer software to identify changes in a tumor’s size and location to allow for changes in position of the patient and/or the planned radiation dose. This repetition of imaging can increase the accuracy of the radiation treatment and decrease the amount of radiation to the surrounding normal tissue.

**Stereotactic Radiation and Radiosurgery (SBRT, GammaKnife, and Cyberknife)**

Stereotactic radiotherapy involves delivering a high dose of radiation very precisely to a tumor. Stereotactic radiotherapy delivers radiation from numerous different angles to focus the radiation at one small point, like a magnifying glass. This is similar to IMRT, which is discussed above. Stereotactic radiation involves fewer treatments (called "fractions"). By definition, radiosurgery involves a single fraction and is generally reserved for treatment of lesions within the brain. In contrast, stereotactic radiation involves 2-5 treatments (fractions). By using a large number of unique beam angles to deliver the radiation, stereotactic radiotherapy minimizes the effects on the normal tissue, which the radiation passes through, but delivers a large dose of radiation to a single point where all of the beams converge. However, since the dose of radiation to that single point is so high, very precise targeting of the tumor is required.

**Radiosurgery**

Due to the constraints listed above, the most common use of radiosurgery, with one fraction, involves tumors of the brain. The
brain does not move and hence does not have the problems with motion that other tumor sites can have, and the skull serves as a stable landmark for the location of the tumor. Generally, a head frame or halo needs to be attached to the skull using small screws. This allows the head to be positioned with great accuracy in the treatment machine and allows the precise delivery of the radiation in a single treatment. With the frame on, the person undergoes an MRI scan to localize the tumor and the frame serves as a stable landmark for the location of the tumor. The MRI is then used to plan the radiation treatment using specialized software. The tumor and normal structures are outlined on the MRI and a treatment plan is constructed to avoid critical brain structures while giving an optimal dose to the tumor. Because the MRI was taken with the frame on, the tumor location within the frame should be the same on the treatment machine. The frame is then attached to the treatment machine and radiation can be delivered with sub-millimeter accuracy. Several different machines can be used to deliver radiosurgery, including GammaKnife machines and specialized linacs. Radiosurgery is limited by the need for precise immobilization of the tumor, such as with a head frame (see photo below) and by the size of the lesion that can be treated. Because of its complexity, radiosurgery requires the participation of both neurosurgery and radiation oncology during treatment planning and delivery. Due to the small focal spot of highly intense radiation used in radiosurgery, only lesions under 5 centimeters are treatable with this technique.

**Stereotactic Radiation**

Stereotactic radiation, also referred to as stereotactic body radiation therapy (SBRT), involves the precise delivery of radiation in 2-5 treatments. SBRT can be used in many sites of the body, including lung, prostate, liver, brain, and bone. With major improvements in technology, computers, imaging, and immobilization over the past decade, radiation oncologists now have the option of treating some tumors with fewer numbers of fractions. Similar to radiosurgery, computer technology creates and controls numerous beams with MLC's to create very sharp dose gradients with tumors receiving large doses of radiation, while sparing the nearby normal organs. Because of the steep drop-offs in radiation dose, very precise targeting must be performed. Immobilization is critical for accurate targeting and reproducibility in each treatment. Markers, referred to as fiducials, are often placed prior to the simulation to help in accurately locating the same treatment area on a daily basis. Finally, because tumors move with breathing, your radiation oncologist will compensate for respiratory motion during the actual treatment delivery. Stereotactic radiation can be delivered by some linear accelerators as well as the CyberKnife system. CyberKnife is unique in that it is a linear accelerator placed on a robotic arm, giving it many degrees of freedom. The robotic arm enables the CyberKnife to treat tumors from a variety of angles, further minimizing exposure to normal tissues. Additionally, the advanced technology of CyberKnife allows to it track tumors in real-time, overcoming respiratory motion and further reducing normal tissue exposure.

**Brachytherapy**

Brachytherapy involves the use of a radioactive source, generally one that predominantly emits photons. The source is either implanted into the tumor (*interstitial brachytherapy*) or placed near the cancer, generally in a body cavity (*intracavitary brachytherapy*). Prostate seeds are an example of interstitial brachytherapy, where radioactive seeds are placed directly into the prostate using needles. Uterine cancer treated with a removable implant (called tandem & ovoids) placed in the uterine cavity through the vagina is also an example of intracavitary brachytherapy. The advantage of brachytherapy is that since the source of the radiation can be placed in, or adjacent to the tumor, the amount of normal tissue affected by the radiation can be minimized. This is because the dose of radiation released from the source is very high near the source itself, but the dose falls off rapidly within a few centimeters. This limits brachytherapy to cancers in locations where a radioactive source can be inserted safely, but still treat the tumor effectively. Brachytherapy is not effective for treating large areas or deep tumors unless the source can be implanted correctly.
Implanting prostate brachytherapy "seeds"

Radiation "seeds" used for prostate brachytherapy

Applicator for cervical HDR

X-Ray of tandem and ovoids apparatus (white & gray piece) inserted for endometrial cancer brachytherapy.

**Orthovoltage Radiation**

Orthovoltage was commonly used before the development of linear accelerators for the treatment of a variety of tumors. Orthovoltage radiation uses lower energy photons to treat tumors, which are located on the skin or very close to the skin. The lower energy of orthovoltage beams makes them impractical in the treatment of deep tumors compared with the higher energy beams available today with most linacs. However, orthovoltage treatment can be very effective for some skin tumors and other superficial lesions. Orthovoltage units are becoming rare, as many of the treatments that were done previously by orthovoltage units are now treated with electrons.

**Electron Radiation**

Electrons are a different form of radiation than photons and have different physical properties, but work biologically the same as photons. Linear accelerators, in addition to producing photons, can also produce electrons; consequently electrons are available at most treatment centers. Electrons tend to release their energy close to the skin's surface and are commonly used to treat superficial tumors, such as skin cancers and superficial lymph nodes, which may be involved with tumor, such as in breast cancer. Electrons have the advantage of releasing most of their energy near the skin; hence the radiation does not penetrate much past the skin to deeper normal tissues. However, this also limits the depth at which electrons can be used. This treatment has generally replaced orthovoltage because it can be combined in the same machine as a linear accelerator.

**Proton Therapy**

Proton therapy is a type of radiation that utilizes a particle, the proton, to deliver radiation while minimizing dose to nearby organs. The prevalence of proton therapy has dramatically increased in the past decade as technology has improved. However, this treatment is still not widely available because the machines that produce and deliver protons, are extremely large (about 3 stories in height), require dedicated space and are very expensive. Smaller machines are in development, which is expected to make this treatment available in more locations.

The advantage of protons is that the depth at which they release their energy can be precisely controlled. As the proton enters
the body, it releases small amounts of energy, and slows down. At the end of its path, it releases a large amount of energy, and very little energy is released past that point. Using computer software, the protons can be directed to release their energy precisely within the tumor, without any of the energy exiting out of the back of the tumor. Hence, if the back edge of the tumor is located against the spinal cord, it may be possible to spare any radiation dose to the spinal cord using protons. The disadvantages to protons are mostly related to their limited availability, which may delay or preclude treatment for patients who require expedient treatment. Due to the high cost of proton therapy, some insurance companies may not approve payment of this treatment.

Summary

This article has outlined several different types of radiotherapy, as well as some of the various advantages and disadvantages of each. No one type of radiation is perfect for every situation. Radiation oncologists must take many factors into account, including the individual patient, type and location of tumor, as well as the available clinical evidence when selecting the optimal treatment modality for a person. We hope that this article has given you a clearer understanding of the various types of radiation available, and the rationale behind the selection of a specific modality for each individual patient.

Figures

Figure I. Shown on the right is a single cross sectional image from a CT scan. The red arrows indicate where the radiation oncologist has circled the kidneys, which have a low tolerance for radiation. The figure on the left shows that by combining these outlines, the kidneys can be seen in a reconstructed image of the person in a standing position, hence the position of the kidneys can be seen in all three dimensions. The radiation beams passing through the center have been position to avoid the kidneys while optimally covering the tumor.

Figure II. Shown in green are the leaves or multileaf collimator (MLC’s) used to shape radiation. As you can see, each leaf can be moved independently to form shapes. The kidneys are being shielded (pink and green structures) while maximum dose is
Figure III. Shown is a single cross sectional image from a CT of the head that is being used to plan Intensity Modulated Radiation Therapy (IMRT). The blue line encompasses areas which are at risk for tumor involvement. The red and green lines indicate where the radiation oncologist wants a higher dose of radiation directed because these areas had definite tumor involvement. The light blue line outlines the spinal cord, which indicates to the software that we want to protect the spinal cord.

Figure IV: Demonstrates how the dose of radiation can be shaped to avoid normal organs using IMRT. The highest doses are in red with lower doses in blue and green. Notice that the spinal cord has been protected and is green (red arrow), indicating it is getting a low dose of radiation compared with the red areas where the tumor was known to be, which is covered with a high dose of radiation.