Classroom notes for: Radiation and Life

98.101.201
Thomas M. Regan
Pinanski 207 ext 3283
Nuclear Medicine as a Therapeutic Tool

- As mentioned, nuclear medicine can be used as a diagnostic tool, as we’ve discussed, and it can be used as a treatment tool, primarily for treating cancer.
- Note that the term “radiation therapy” means the same as “nuclear medicine as a therapeutic tool”; the two terms will be used interchangeably in the material that follows.
  - An informal definition of cancer is: the uncontrolled division of cells leading to a breakdown in the function of the tissue in question.
  - The great majority of cancers originate on the surface of some tissue or organ. \cite{Hall, 123}
  - Initially, the cancer is “localized”, and is found only on the lining or in the underlying tissues. \cite{Hall, 125}
- The cancer cells can spread through the lymph channels or the bloodstream to other parts of the body.
- This is known as metastasis. The exact causes of cancer are hard to demonstrate.
Broadly, it can be stated that “environmental agents” (both manmade and natural) are responsible. (except in the case of smoking, which accounts for a significant percentage of all cancer deaths).

- About 1 in 5 people get cancer.

While it is true that this number is much higher than it was several generations ago, it is also true that people used to die much younger as a result of other diseases; in other words, they didn’t live long enough to get cancer, so no one gave it much thought.

The word tumor is sometimes used to describe a cancerous region. Radiation therapy works as a treatment because ionizing radiation kills cells.

- Cancer cells are more sensitive to ionizing radiation because they divide more rapidly than other cells. A “kill” occurs when cell loses its ability to divide. The cell isn’t necessarily “dead” in the way you normally consider the concept, it simply can’t divide. Essentially, the goal of subjecting a tumor to ionizing radiation is to prevent further growth/spreading.
The cancer must be localized for radiation therapy to work; this way, the radiation dose will also be localized.

If cancer has spread throughout the body, to kill all of the tumors, the entire patient’s body would eventually be subjected to very high doses, potentially enough to kill the patient as well as the cancers.

Radiation therapy for cancer can be a superior alternative to surgery for two reasons.

Success rates are equal or higher in certain cases.

Typically, the organ is preserved intact and there is little or no disfigurement.
Consider cancer of the larynx.

- As of 1984, 90% of patients could be cured with radiation and retain their natural voices (the numbers may be even better now).
  - Surgery typically impairs speech.
  - As of 1984, roughly ½ of all cancer patients received radiation therapy, while about 1/8th of all cancer patients were cured using nuclear medicine; this was known as the ½ x ½ x ½ rule at the time. *(Radiation and Life, Hall, p. 126)*
  - There is a small but quantifiable risk of the treatment causing cancer later in life.
  - Dr. Joseph Neglia of the University of Minnesota presented results from the most recent study linking cancer treatment to secondary disease. His data show that 3% of 13,581 people who had cancer treated before age 21 developed a cancer later in life that was not a relapse of the original disease. Study participants were followed an average of 15 years after initial cancer treatment, with some followed as long as 20 years. *(NECHPS Newsletter, Volume XXXVII, No. 7)*
– Consider risk vs. benefit. The risk is a cancer later in life caused by radiation therapy, the benefit is treatment of a current tumor that otherwise threatens the person’s life immediately. (NECHPS Newsletter, Volume XXXVII, No. 7)

♦ There are two types of treatment.
♦ External treatment modes involve beaming ionizing radiation at the patient from a source outside the body.
♦ The radiation used is typically x- or γ-rays, but other types of external beams are used on occasion.
♦ Internal treatment modes involve placing a radioactive material (implant) inside the body.
Internal Treatment Using Radioactive Implants

- Inserting radioactive implants is known in the medical community as “brachytherapy”.

- The tumor must be relatively small; you would have to put too much radioactive material in the patient for large tumors, to the extent that healthy tissue might also be harmed.

- The tumor must be accessible by surgery. Obviously, if radioactive materials are to be implanted in the body, surgical procedures are necessary to put them there.

- Roughly, about 1 in 20 patients have cancers that satisfy these two conditions.

- One example of an implant is iridium-192 wires. Iridium is a relatively soft metal, so little discomfort is caused when it is inserted. The wire is left in place for 3-10 days.
  - Obviously, then, two procedures are required, one to insert the wire, and one to remove it.


Another example is I-125 “Brachytherapy seeds”.

- The “seeds” are small grains of radioiodine.
  - Brachytherapy is Latin for "short distance."
- The seeds are left inside the patient and eventually decay away to stable iodine.
- The half-life is 60 days, so within a year or two the radioactivity is essentially negligible.
- This method is widely used to treat prostate cancer.
- Traditional surgical removal techniques for prostate cancer run the risk of leaving the patient incontinent, impotent, or both. The surgical procedure for inserting the seeds at the prostate gland involves a much lower risk of damage.
CT slice showing implanted seeds

http://www.prostatecancerexperts.com/brachytherapy/brachytherapy_information.html
External Treatment

Beams of photons or charged particles are directed at the patient’s tumor from a source outside the body.

♦ In the process, healthy tissue is irradiated.
  – This is inevitable, because healthy tissue is between the beam and the tumor.
  – If just one beam is used, and it is strong enough to kill the cancer cells in the tumor, then it will be strong enough to kill the intervening healthy tissue. Obviously, this is undesirable, so there must be a strategy to maximize the dose to the tumor, while minimizing the dose elsewhere.

♦ To minimize dose to healthy tissue, dose fractionation is applied. Instead of one strong beam, many weak beams are used. This could be one weak beam applied many times from different directions over the course of days or weeks.
This could be several weak beams applied simultaneously from different directions (the so-called “cross-fire” technique). In either case, the tumor is the focal point, and receives the combined dose from all of the beams, while any particular portion of healthy tissue will only receive “one beam’s worth” of dose.
X-ray machines are one way to treat patients

♦ These machines operate on the same principal as diagnostic x-ray machines; the x-ray energies produced are simply much higher.

♦ In other words, these are bremsstrahlung x-rays generated by a machine; there are no radioactive materials involved, and when the machine is shut off, the x-ray beam is gone.

♦ The first therapeutic application of x-rays, according to Emil H. Grubbe, was on Wednesday, 29 January 1896 to treat a cancer of the left breast in Mr.s. Rose Lee. Grubbe was a student at Hahnemann Medical School in Chicago.

*(The Health Physics Society’s Newsletter, October 1997, p. 11)*
γ-rays from the decay of cobalt-60 are another external treatment form.

- The cobalt-60 is a radioactive material housed within lead shielding. Shuttered holes are used to direct the beams, which are then directed at the tumor.
- The “gamma knife” at New England Medical Center is an example of a device that sends multiple beams at the patient simultaneously. It looks like a big dome that fits around the patient’s head.
- It is interesting to compare the two external treatment forms just mentioned.
  - X-ray machines don’t require the storage of radioactive materials, because they are machines. However, as machines, they require upkeep and maintenance, and can break down.
  - Cobalt-60 sources are “passive” devices without the technical complexity of x-ray machines, and as such are easier to maintain. However, since cobalt-60 has a 5.27 year half-life, it will eventually loose it’s strength as a source and will need to be replaced.
Proton Beams

♦ Proton ($p^+$) beams can be made in particle accelerators.
  – A particle accelerator is a machine that uses magnetic fields to boost charged particles to tremendous energies (remember Oersted, Faraday, and Maxwell - this will only work for charged particles).

♦ For $p^+$, most of the dose is delivered at the end of the path.

♦ Recall that as charged particles, protons are a form of directly ionizing radiation, which experiences the greatest energy loss (and delivers the greatest dose) at the end of the path. The intervening healthy tissue before the tumor receives much less dose.

♦ The proton beam can be adjusted to ensure the point where it delivers the greatest dose coincides with the exact depth at which the tumor is located.

♦ There is a proton beam therapeutic unit at Mass General Hospital; (as of 1/29/02) it is one of only two operational units of its kind in the United States. (WBZ Channel 4 Five O’clock News, Health Matters, 1/29/02)
Heavy Ion Beams

♦ It is possible to accelerate charged particles more massive than protons.
♦ These “heavy” ions are simply nuclei stripped of electrons.
♦ It is harder to accelerate these ions, and their penetration depth isn’t significant unless they have very high energies.
♦ The dose profile inside the patient is similar to that of proton therapy.
Dose distribution:
concentrates at the end point
(Bragg peak)

Heavy ion, Proton
• Low LET at Surface
• High LET at End of Range

Carbon beam is High LET radiation.

Gamma-ray, Neutron
• from Surface to End point
  = constant LET

(LET: Linear Energy Transfer keV/μm)
Dose distribution at the tumor

- Heavy ion therapy
  Uniform dose-distribution
  Small dose behind target due to fragmentation

- X-ray therapy
  Irradiation from various directions is necessary.
  Improved method -> IMRT

http://www.na.infn.it/IJsymposium/Torikoshi.pdf#search='HEAVY%20ION%20THERAPY'
Neutrons

♦ The process of destroying tumors with neutrons is a multi-stage process.
♦ The tumor (usually in the brain) is removed surgically. The patient is then injected with a compound containing the amino acid phenylalanine.
♦ Any remaining cancerous cells will be “greedy” for this compound, and absorb it at about four times the body’s normal rate.
♦ The compound also contains stable boron.
   – The boron is not radioactive.
   – Neutrons in the 1 eV to 10 keV range are then beamed at the tumor.
   – These neutrons are in the so-called “epithermal” range.
Remember that neutrons interact only with the nucleus; thus depending upon their specific energies and the target nuclei in question, the neutrons will interact quite readily with some materials and almost not at all with others.

In the case of epithermal neutrons traveling through the brain, they will scatter off of hydrogen atoms (in H₂O) in the brain and will be reduced in energy.

Because the neutrons must travel through healthy tissue, the treatment is more successful if the tumor is near the scalp. (Boston Globe)

At the tumor, the neutrons are now at the lowest energies (~.025 eV), and are readily absorbed by the boron in the tumor.
The boron emits alpha particles as a result of absorbing the neutrons.

\[ _5^{10}\text{B} + _0^1\text{n} \rightarrow _3^7\text{Li} + _2^4\text{a} \]

- The alphas are very damaging to the tumor in which they’re created, but they have such a short range that they don’t penetrate to the healthy tissue beyond.
- One type of tumor that can be treated is glioblastoma multiforme, which strikes about 7,000 Americans a year. (Boston Globe)
- Neutron capture therapy (NCT) was first tested at Brookhaven lab and Massachusetts Institute of Technology in the late ‘50s and early ‘60s. But then, (Dr. Jeffery) Coderre said, “The side effects were unacceptable, and the success rate was low. The drugs were not selective for the tumor.” (Boston Globe)
Therapy Strategies

For any cancer, the best alternative is considered.
- Radiation therapy is an option.
- We’ve discussed the conditions that allow for successful use of this treatment form.
  - Surgical removal may present the easiest option.
  - If the cancer is widespread, chemotherapy may present the best option.
  - Chemotherapy is the use of drugs to treat cancer.
  - A single drug may be used, but more often, many are used.
  - Some common side effects of chemotherapy include fatigue, nausea, vomiting, and hair loss (alopecia).
  - Chemotherapy involves drugs, not ionizing radiation, so it is separate and distinct from nuclear medicine, which does use ionizing radiation; please distinguish between the two. It is a common misperception that “chemo” patients have lost their hair because of radiation.
In reality, the best option will often involve a combination of some or all of the treatment methods just mentioned.

For instance, a tumor may be surgically removed then radioactive seeds implanted to ensure destruction of any remaining cancerous cells.

For an excellent account of cancer therapy from the patient’s viewpoint, read *Songs from a Lead-Lined Room* by Suzanne Strempek Shea.

**Average Doses**

<table>
<thead>
<tr>
<th>therapeutic procedure</th>
<th>dose in mrem (per procedure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>barium enema</td>
<td>405</td>
</tr>
<tr>
<td>upper GI</td>
<td>245</td>
</tr>
</tbody>
</table>
Average Occupational Doses

- The annual occupational dose to radiology technicians is about 300 mrem/yr. (http://www.em.doe.gov)
  Compare that with the previously listed occupational doses.
- 500-900 mrem/year for subsonic aircraft crew,
- 800-1700 mrem/year for supersonic aircraft crew, and
- 1700-14,400 mrem/year for astronauts in earth orbit. (Heath Physics, November 2000, p. ?)
- Remember, occupational doses are actually included in the final category “Other”.
Other Sources of Manmade Dose (~1 mrem/yr- <1% of total) (NCRP 93)

- “Other” includes: occupational (<.3%); nuclear fuel cycle (<.03%); fallout (<.03%); and miscellaneous (<.03%) (NCRP 93)
- The category “Other”, though it represents the smallest portion of the pie chart, contains perhaps the two most controversial uses of ionizing radiation: fallout from nuclear weapons detonations and commercial nuclear power generation.
- A discussion of the production and use of nuclear weapons production, though scientifically interesting, is much better carried out in the context of a politic science or international relations class, so will only be briefly touched upon this semester.
- For close to the remainder of the course, we’ll focus on the portion of “Other” represented by commercial nuclear power generation.