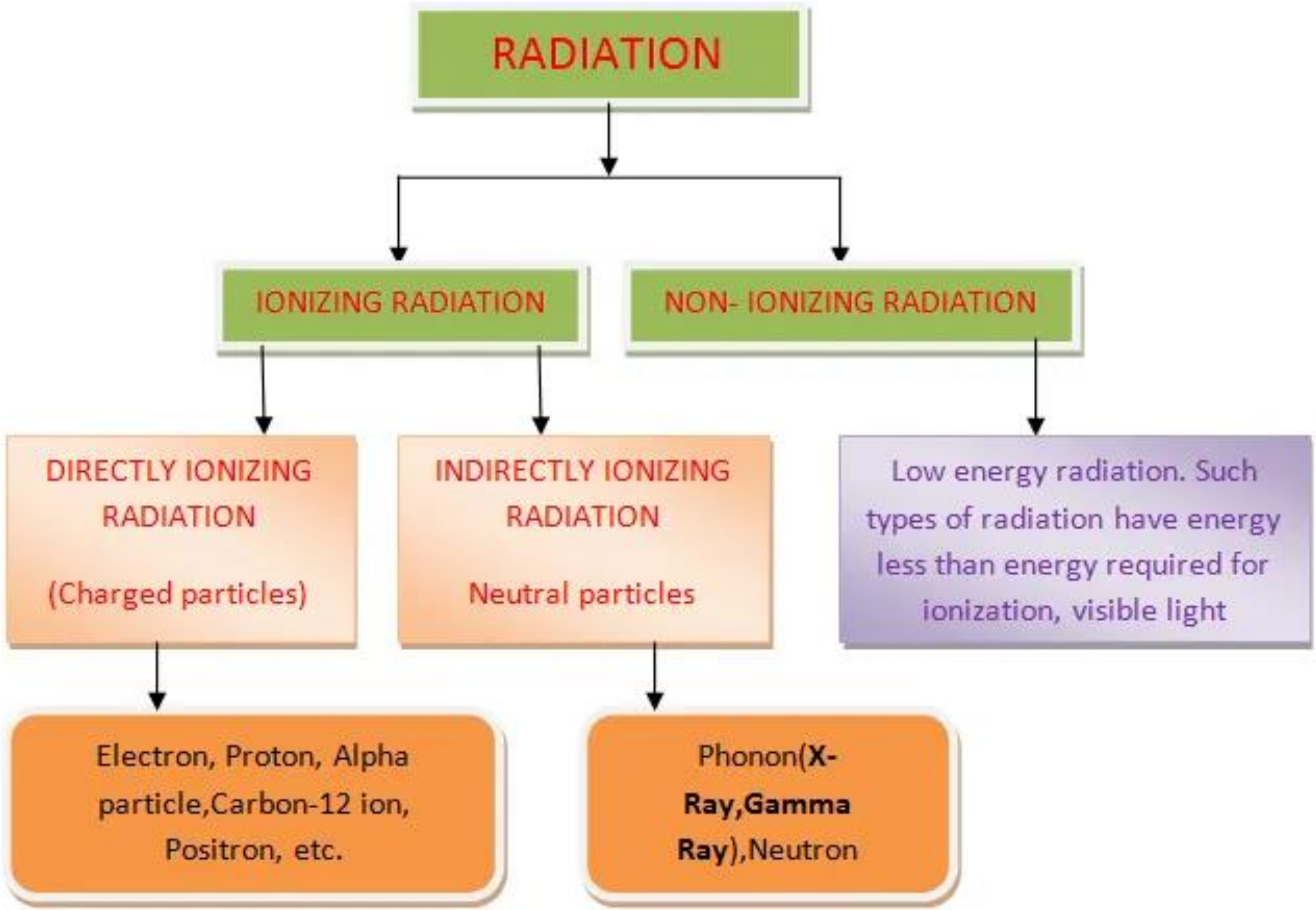
Proton Beam or Photon Beam Radiotherapy: Which One is Better to Treat Cancer?

العلاج الإشعاعي بأستخدام شعاع البروتون أو الفوتون: أيهما أفضل لعلاج السرطان؟

Dr. Amal Yousif Al-Yasiri

College of Dentistry- University of Baghdad

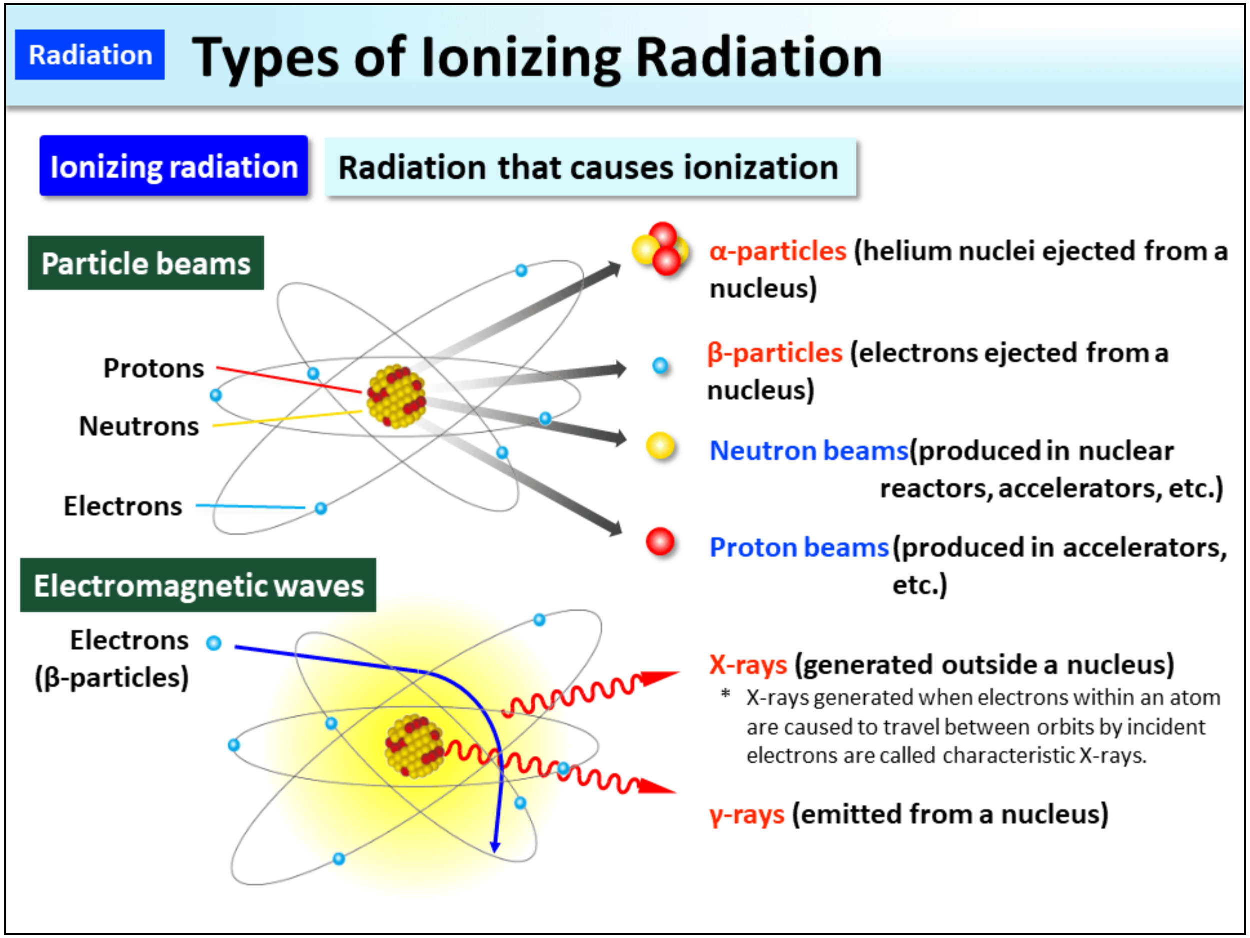
Types of Radiation



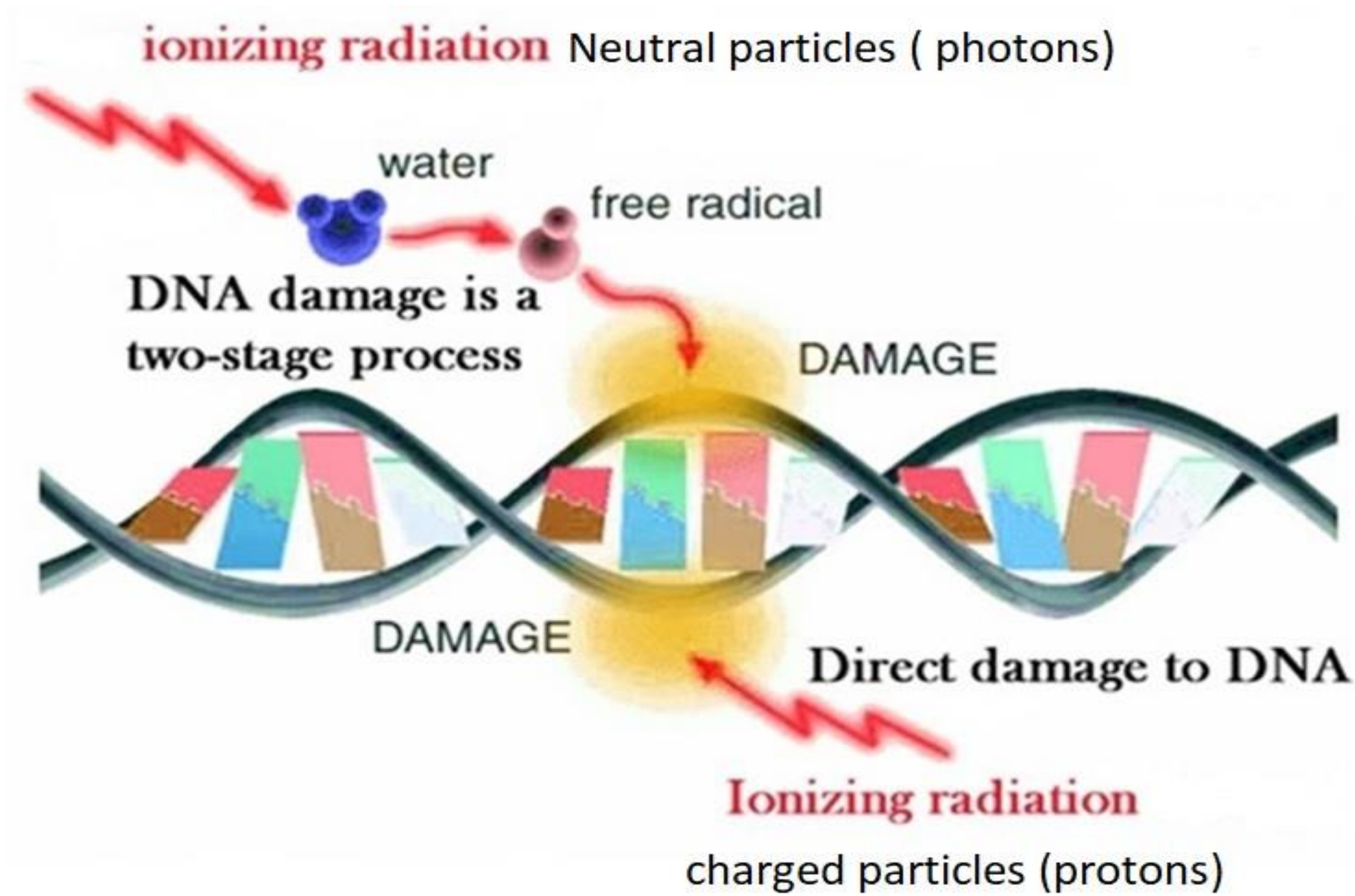
Ionizing radiation

Ionizing radiation is radiation with enough energy that can remove tightly bound electrons from the orbit of an atom, causing that atom to become charged or ionized. lead to the formation of ion pairs

Only ionizing radiation is used in radiotherapy



Ionizing Radiation Damage to DNA



Radiotherapy Goal

- The main goal of radiation therapy is to determine the optimal dose of radiation to the cancerous tissue with minimal damage to normal tissues located in the area of exposure.
- Several radiotherapy modalities use ionizing radiation to treat cancer. In this lecture, I will focus on photon therapy that uses high energy X-ray beam (Linear accelerator), and proton therapy that uses proton beam and see which one is better to kill cancer cells and spare normal cells
- Both linear accelerator and proton therapy are are considered as External beam therapy (EPT)

Photon therapy (linear accelerator)

Photon therapy (linear accelerator)

- A medical linear accelerator (LINAC) is a machine that is used to deliver high-energy x-rays to a tumor volume and destroy cancer cells while sparing surrounding normal tissues.
- The high energy x-rays (photons) are shaped as they exit the machine to conform to the shape of the patient's tumor
- Used to treat all parts and organs of the body
- High energy photons enter the patient's body and aim to break the DNA in all the cells within the treatment area
- The normal cells are able to mend themselves
- The cancerous cells are unable to do this and therefore die

The behavior of photon beam when it enters the patient body

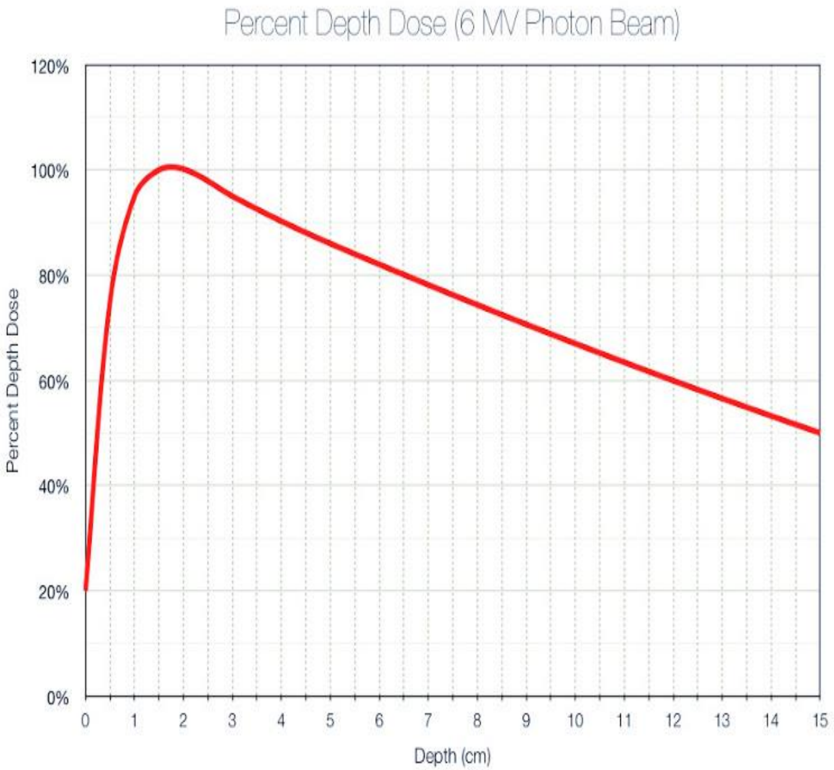
- Photons are neutral (no charge), therefore they are able to penetrate most common mediums such as the human body

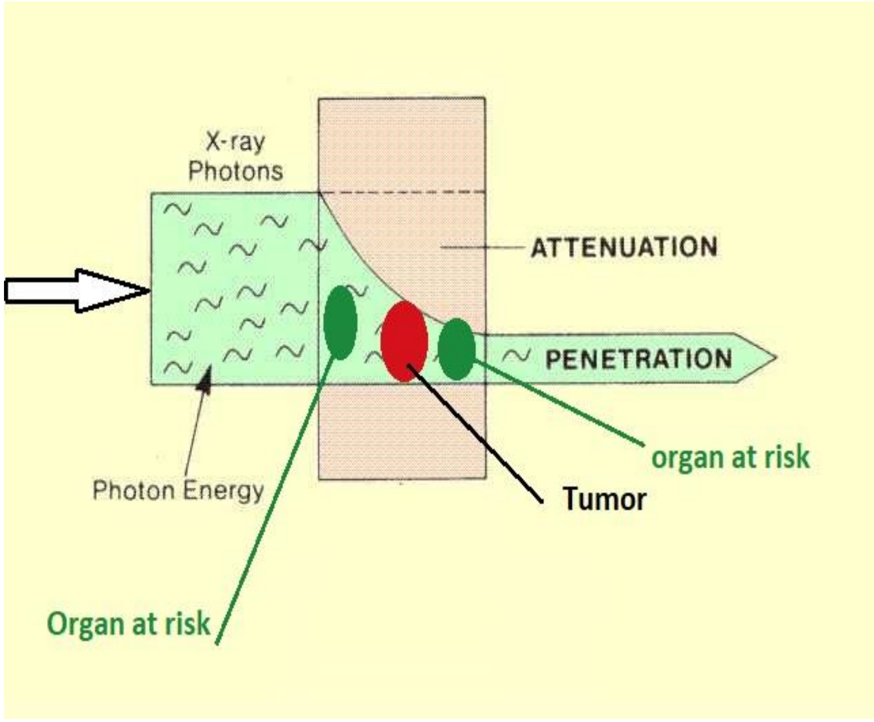
- Each photon either makes one interaction and gives most or all of its energy or can pass without making any interaction

- When a photon beam with particular energy enters the human body, it will interact with the atoms and ionize them (ion pairs)
- Due to these interactions, the energy of photon beam will attenuate exponentially (will not reach zero)
- The entrance dose will be high. Then, number of photons gets attenuated as depth increases. As their number decreases, the dose that they deposit decreases also (proportionately). However, There is always a significant exit dose

- Some of the energy of the photon beam will be absorbed by the tissue that passing through

The behavior of photon beam when it enters the patient body



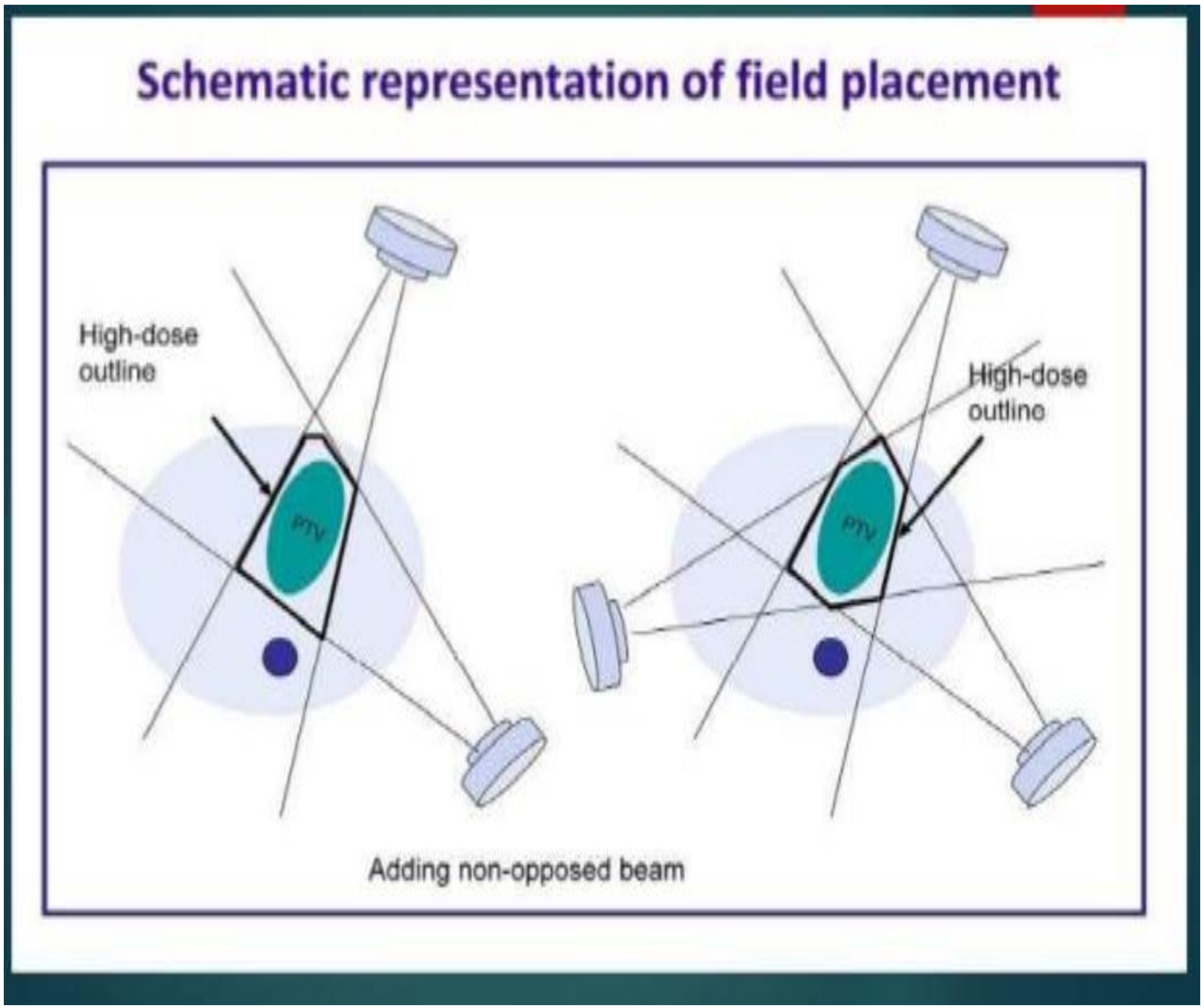


If the patient receives one single photon beam, the normal organs in front of the tumor will get more dose than the tumor itself. So, how can we solve this problem?

The behavior of photon beam when it enters the patient body

- The problem was solved by
- 1- Dividing each radiation treatment into separate beams (delivers a unique pattern of radiation).
- 2- Fractionation of dose (it is the method where total prescribed dose is divided in small fractions and given over a period of time)
- The highly conformal radiation dose maximizes radiation to the tumor while minimizing exposure to healthy structures
- But still, some radiation dose will be delivered to normal organs that close to the tumor

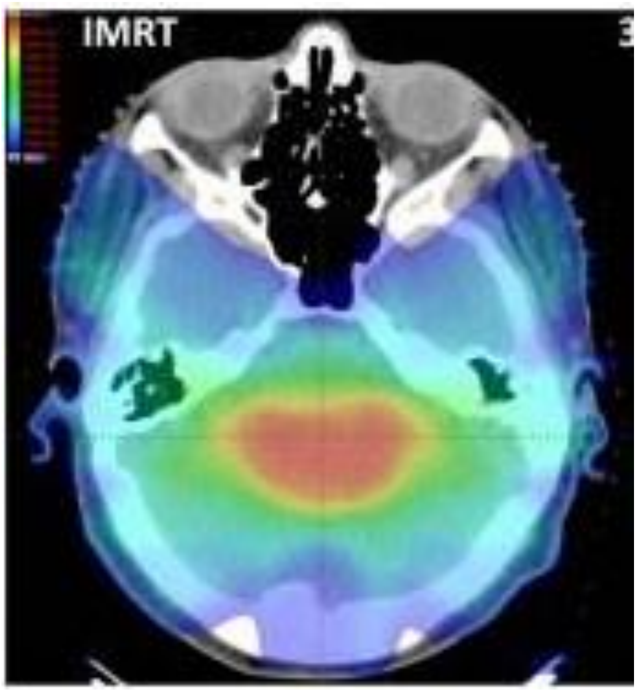
The behavior of photon beam when it enters the patient body



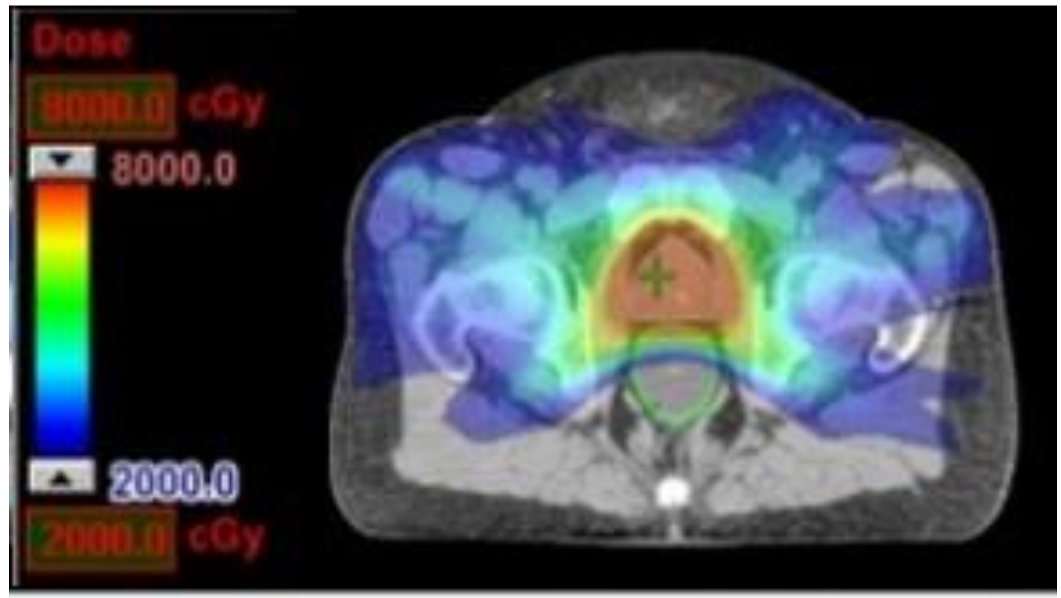
Is the photon beam an optimal modality to treat all the tumors?

- Just a reminder, the radiotherapy goal is to maximize the radiation dose to the tumor and spare the healthy tissue
- Therefore photon beam is not the optimal modality to treat cancer located deep inside the body and surrounded by several normal organs such as prostate cancer, neck, and head cancer, lung cancer, and cancers in children

Is the photon beam an optimal modality to treat all the tumors?



Brain tumor



Prostate tumor

No, it is not for these two tumors

- Is there another modality that is optimal to treat these types of cancers and spare normal organs from receiving any unwanted radiation?

- Yes, there is. (This modality is Proton therapy)

Proton Therapy

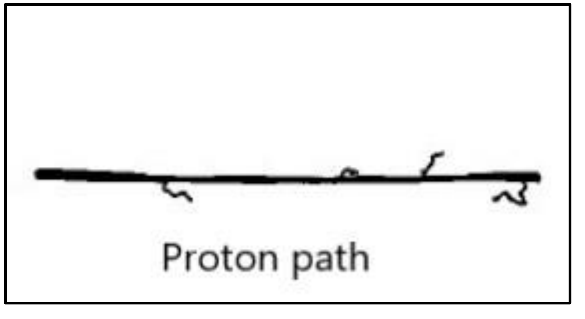
https://www.youtube.com/watch?v=hyZxWuQ6ZrE

History of Proton Therapy

- Physicist Robert Wilson at Harvard University made the first proposal in 1946
- Accelerated protons should be considered for radiation therapy
- Maximum radiation dose can be placed into the tumor
- Proton therapy provides sparing of healthy tissues
- The first patient treated with protons was in 1955 at Lawrence Berkeley Laboratory
- As of 2019, about 94 facilities worldwide are using proton beams for radiotherapy.

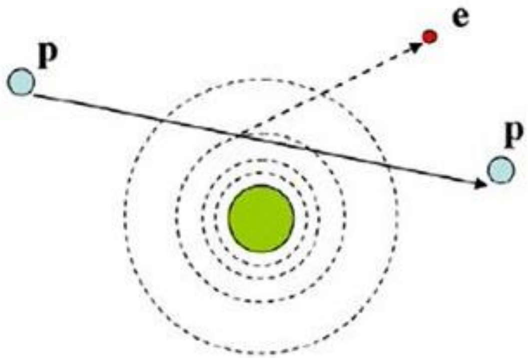
Characteristics of protons

- Subatomic particle (Proton is the nucleus of the hydrogen atom)
- Stable
- Positively charged (+1)
- Heavy particle with mass 1800 that of electron
- They travel in straight lines. Very little scattered as they travel through tissue



Interactions of Protons

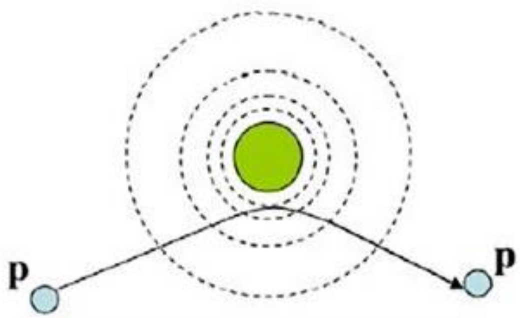
1. Inelastic Coulomb interaction with atomic electrons



Dominating interaction:

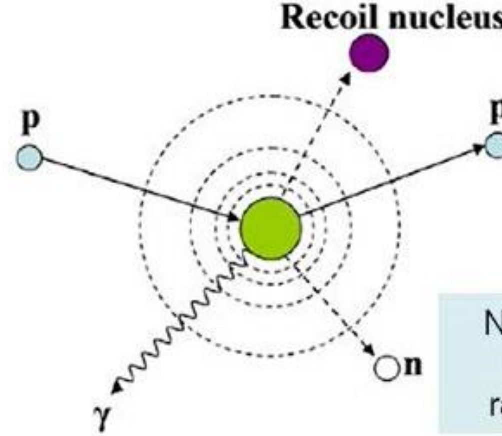
- Ionization **(=dose)**
- Small energy loss per interaction ⇒ **Continuous slowing down of proton ⇒ Well-defined range**
- Range secondary electrons < 1mm ⇒ **Dose is absorbed locally**
- **No significant deflection** of protons ($m_p = 1832 \cdot m_e$)

2. Elastic coulomb scattering with nucleus



Lateral scattering of treatment field versus depth

3. Non-elastic nuclear interaction



Neutrons are the main external radiation hazard

Interactions of Protons

Protons interact with atomic electrons and nuclei in the medium through

1- Inelastic Coulomb interaction with electrons

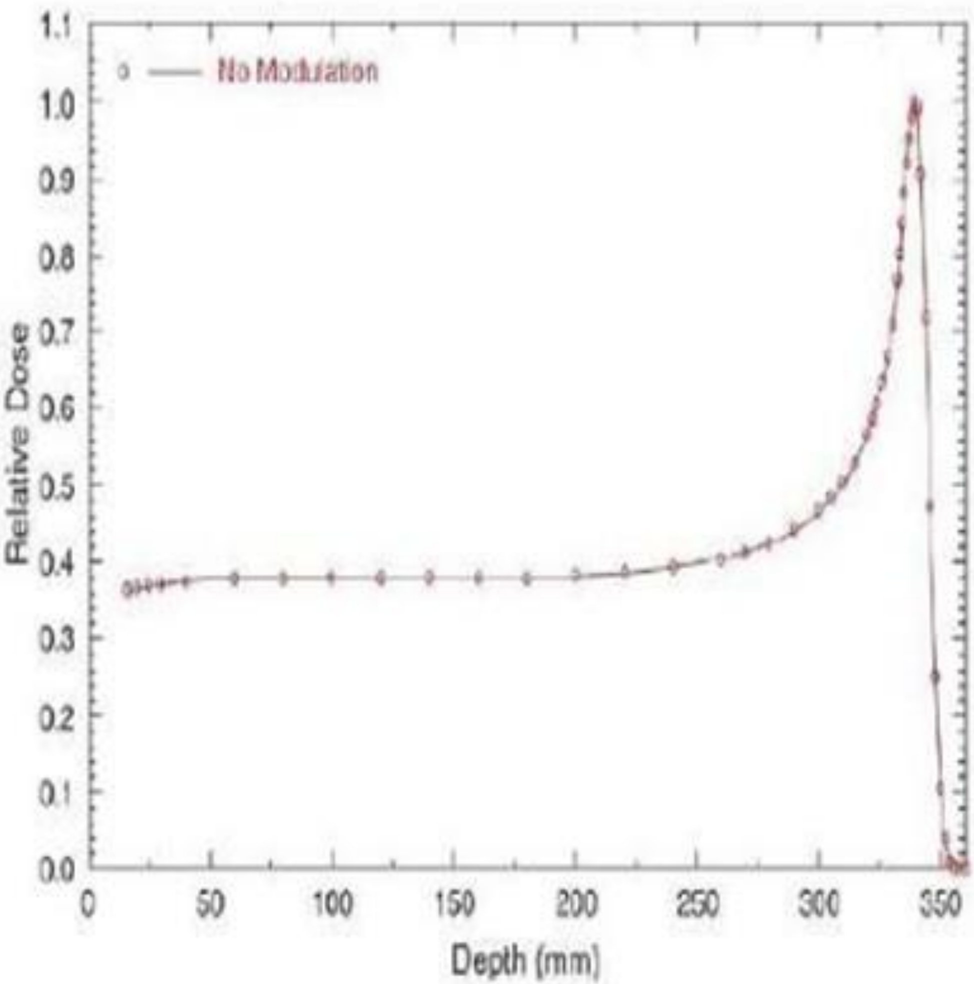
2- Elastic Coulomb scattering with the nucleus

3- Non-elastic nuclear interaction

- The rate of energy loss due to ionization and excitation caused by a proton travelling in a medium is proportional to the square of the proton charge and inversely proportional to the square of its velocity.
- At the beginning, when proton beam enters the body, it will be energetic and fast
- When the proton travels fast, it loses a small part of its energy In each interaction.
- As the proton velocity approaches zero near the end of its range, the rate of energy loss becomes maximum.
- The sharp increase or peak in dose deposition at the end of particle range is called the *Bragg peak*.

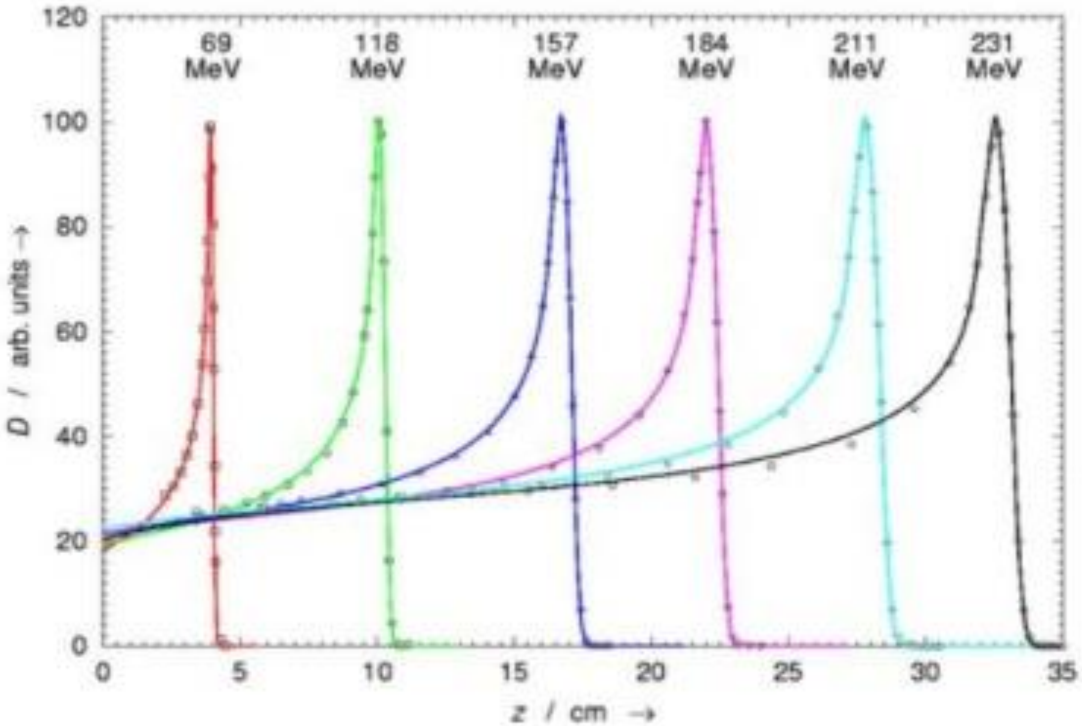
Proton Dose Distribution

- Different modes of interactions Means Different dose distributions
- Low entrance dose (plateau)
- Maximum dose at depth (Bragg peak)
- Rapid distal dose fall-off
- Why this shape of distribution ?



- Protons have the ability of loosing little energy when entering tissue . But depositing more and more as they slow down…..
- Finally, depositing a heavy dose of radiation just before they stop , giving rise to the so-called Bragg peak

Bragg Peak Dependence on Energy

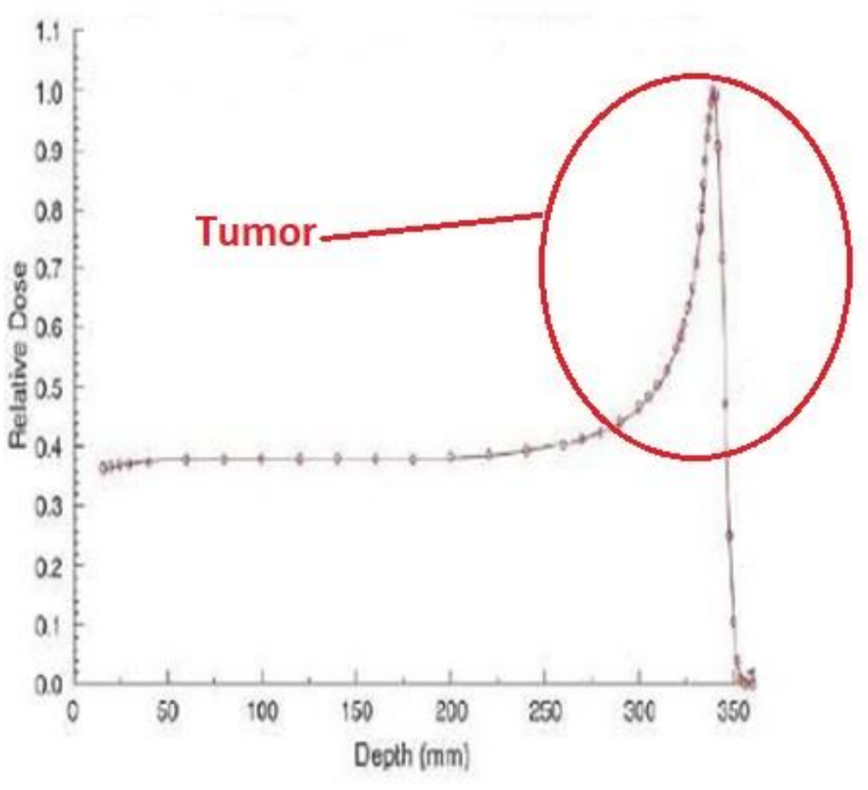


energy (MeV)	*range in water (cm)*
70	4.0
100	7.6
150	15.5
200	25.6
250	37.4

- The *range is* the depth of penetration from the front surface *to* the distal point on the Bragg peak
- Bragg peak depends on the initial energy of the protons so the greater the energy, the further the range
- The physicist must make accurate calculations to concentrate the Bragg peak on the tumor being treated in order to maximize the radiation dose to the tumor while minimizing the dose to the surrounding healthy tissue

Is one proton beam enough to cover the tumor?

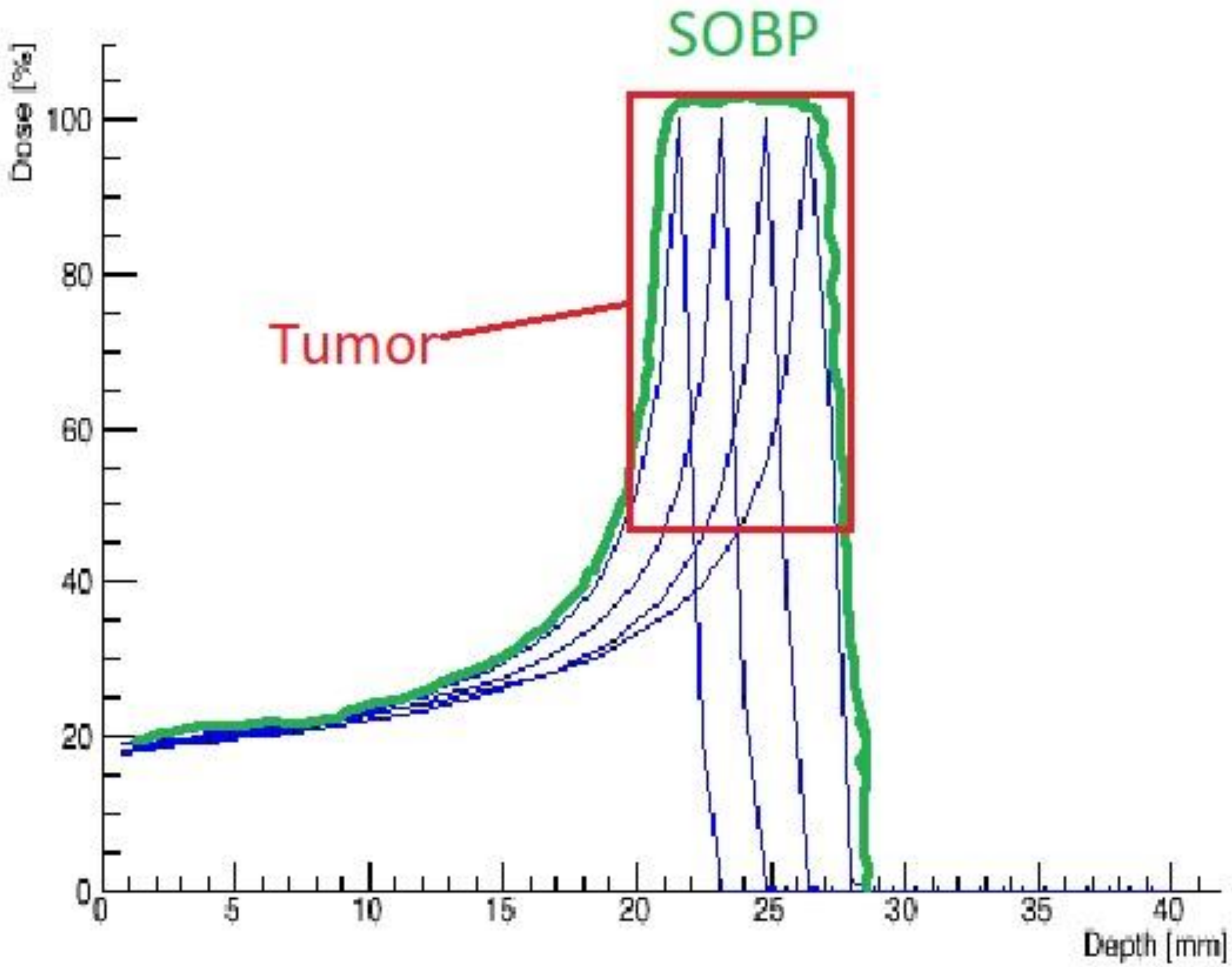
- The answer would be No, it is not enough.
- Because Bragg peak of a monoenergetic proton beam is too narrow to fit the shape & depth of the tumor



What is the solution?

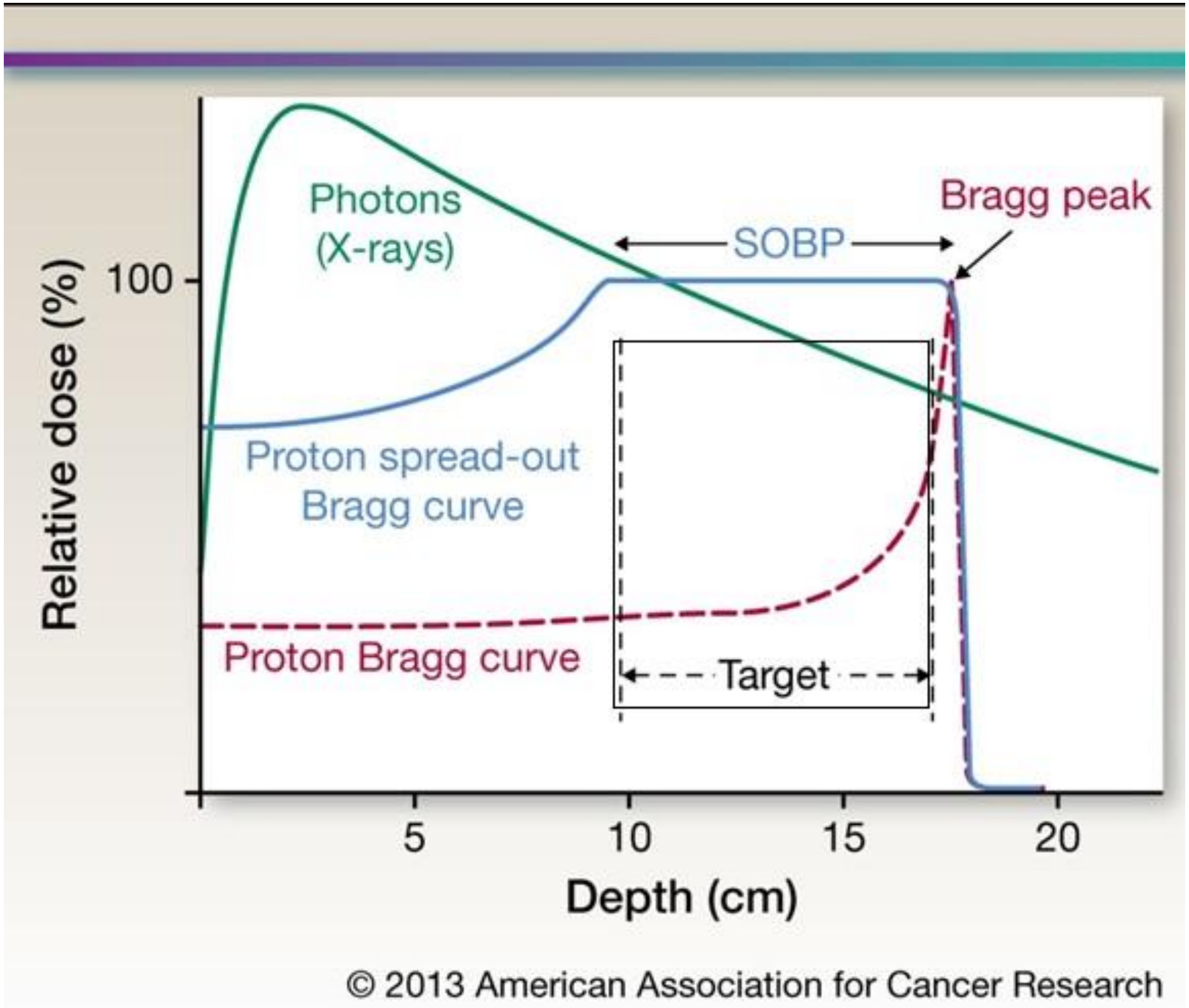
- Increasing the dose in-depth within a tumor volume can be achieved by proton beams of successively delivering not just one, but many Bragg peaks each with a different range (energy)
- In order to provide wider depth coverage, the Bragg peak can be spread out by the superimposition of several beams of different energies called as spread-out Bragg peak (SOBP)

What is the solution?

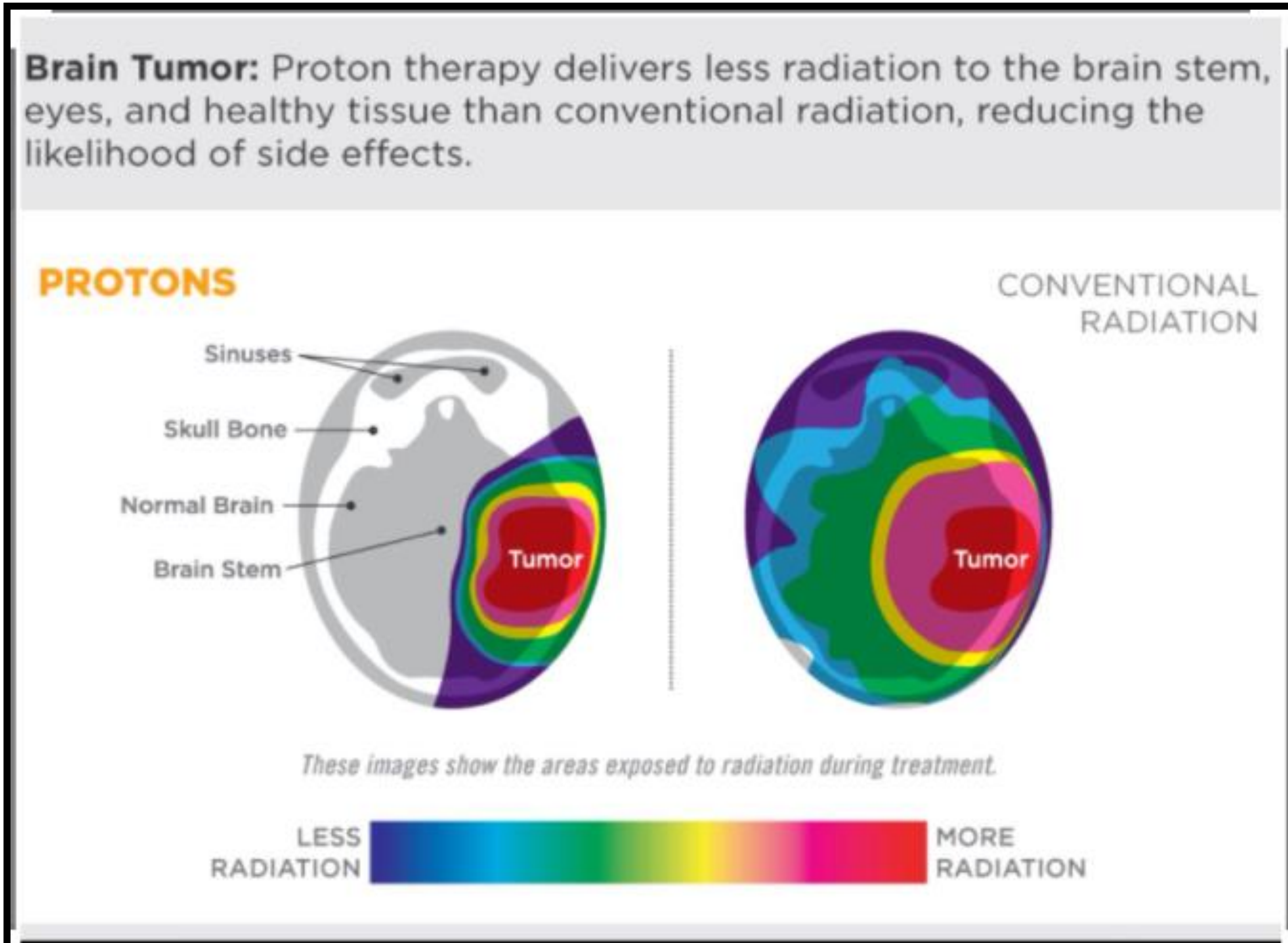


Comparison of dose profiles for photon and proton therapy

The green curve shows the dose profile of a typical 15-MV photon beam. The red curve shows the dose profile of a monoenergetic proton beam. The maximum dose point of this curve is termed the Bragg peak. The blue curve is obtained by electromechanically spreading the monoenergetic proton beam laterally and longitudinally and is used in passively scattered proton therapy. The top flat portion of this curve is called the spread-out Bragg peak. The potential advantages of proton versus photon dose distributions are clear.



Comparison of dose profiles for photon and proton therapy



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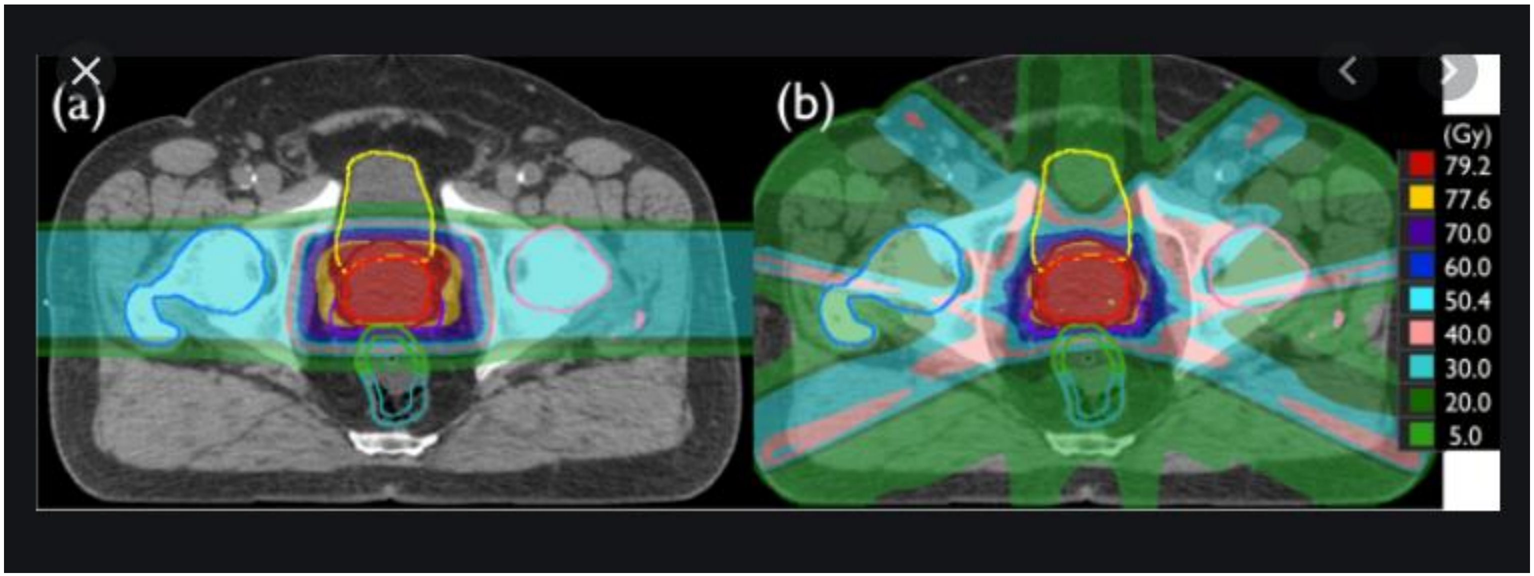
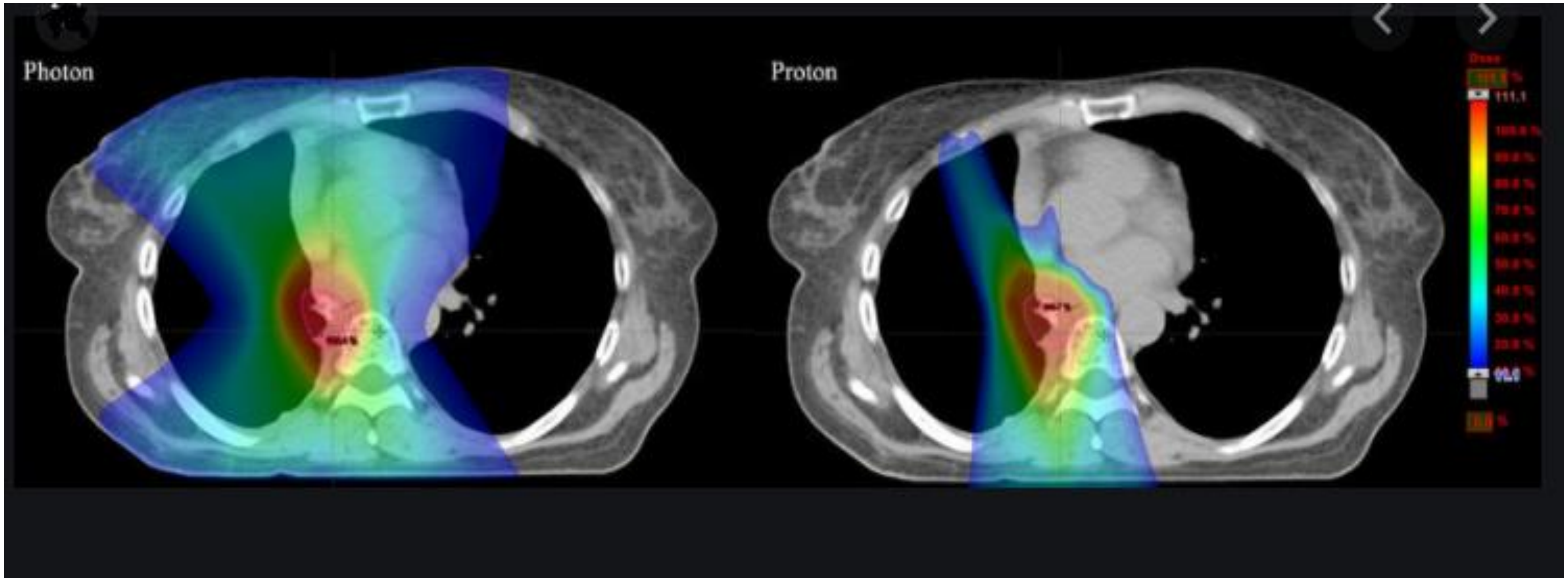


Prostate tumor: Proton therapy delivers less radiation dose to the rectum, bladder, kidneys, and healthy tissues than conventional radiation, reducing the likelihood of side effects

Comparison of dose profiles for photon and proton therapy



Lung tumor: Proton therapy delivers less radiation dose to the heart, spinal cord, and healthy tissues than conventional radiation, reducing the likelihood of side effects

Comparison of dose profiles for photon and proton therapy

Pediatric tumors: Proton therapy would be a perfect choice for all pediatric tumors especially for brain tumor

1- Most children will survive and have a long life expectancy post-exposure
2- Children are at a greater risk than adults of developing cancer after being exposed to ionizing radiation because of their developing bodies

Therefore, normal organs should be protected from any unwanted radiation dose that may induce a second malignancy or cause severe side effects such as blindness, deafness, or loss of memory in case of treatment of brain cancer by photon therapy

Advantages of proton therapy when compared to standard x-ray radiation

1. Fewer short –and long-term side effects
2. Improved quality of life during and after treatment
3. Proven to be effective in adults and children
4. Reduces the likelihood of secondary tumors caused by treatment
5. Can be used to treat recurrent tumors even in patients who have already received radiation
6. Targets tumors and cancer cells with precision, reducing the risk of damage to surrounding healthy tissues and organs

Drawbacks of Proton Therapy

- Limited availability- This treatment requires highly specialized, expensive equipment. As a result, proton therapy is available at just a few medical centers
- Higher expense- Proton therapy costs more than conventional radiation therapy. equipment for production of protons is considerably more expensive than standard radiotherapy equipment

Conclusion

- Proton therapy offers the promise of reduced toxicity to patients compared with photon therapy by reducing the radiation dose to the normal tissues

- The problem lies in its cost factor and availability


Thank you