NUCLEAR PHYSICS IN MEDICINE

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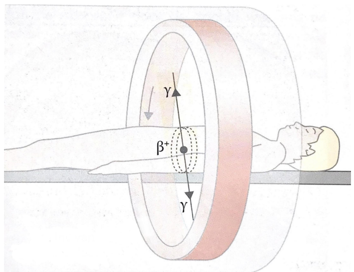
When we think about science healing the human body, we automatically think about biology, the study of living organisms. Nevertheless, have you ever thought about how physics makes a difference in medicine? Our cancer treatments get better and better and the chance of surviving this disease is growing thanks to nuclear physics. We will present some examples of nuclear physics that are playing a role in this improvement.

PET-SCAN

PET, short for positron emission tomography, is a functional imaging technique that uses radioactive isotopes to visualize and measure increased activity of cells.
These different radioactive isotopes, also known as radiotracers, are used for various purposes, depending on the target in the body.

How does it work?

Before you enter the scanner, tracers are injected, swallowed or inhaled, depending on what part of the body is being examined.

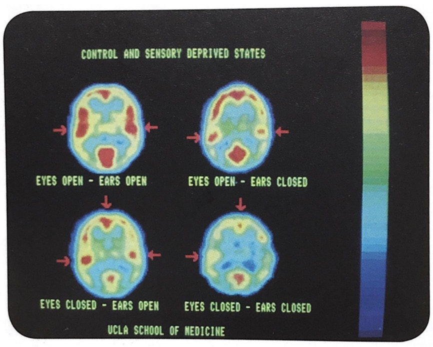


The isotopes most commonly used are Oxygen-15 or Fluorodeoxyglucose-18 and are also known as β+-emitters. The latter is widely used in neuroimaging since it's an analogue of glucose and can cross the blood barrier.

β+-decay will occur when the unstable nuclide converts a proton into a neutron. Positron annihilation will then take place when the positron collides with an electron.
Annihilation converts all the energy into two gamma rays, which are emitted in opposite directions. The gamma rays are detected by the scanner, and an image can then be built up based on where in the body the reaction took place.

Different uses

PET-scans are used to detect cancers. Cancer cells have a higher metabolic rate than other types of cells and because of this reason, a PET-scan is useful to see if cancer has spread, if cancer treatment is working or to check whether or not cancer has returned.



PET-scans also reveal areas of decreased blood flow in the heart. A healthy heart will take in more of the tracer. So depending on the different colours and degrees of brightness, a doctor can indicate different levels of tissue function.

To detect brain disorders, the PET-scan is also used. The brain's main fuel is glucose and during PET-scans the tracers 'attach' to compounds such as glucose. By detecting this radioactive glucose, the PET-scan is able to detect which areas of the brain are utilising the glucose at the highest rates.

Advantages and disadvantages:

Advantages:

To start with the PET-scan: It is one of the safest scans as it has a relatively low radiation dosage. It is painless and only takes about half an hour to complete. The exam is non-invasive and requires no recovery afterwards.

The scans are able to detect diseases before the symptoms show. They can also be used as an alternative to biopsy and other exploratory surgeries conducted to determine how far a disease has spread. Besides all of this, they are the most precise medical tools as they have the ability to differentiate between non-cancerous and cancerous tumours. This makes them more effective and this results in fewer scans and unnecessary surgeries because of wrong staging data and diagnosing. This all results in increased patient comfort.

An extra advantage is the fact that these scans also can be used for diagnosing early stages of other neurological illnesses such as Alzheimer's disease, epilepsy and other mental illnesses.

Disadvantages:

Although the radiation dosage released during a PET-scan is relatively low and the radioactive components aren't long-lasting, the patient is still exposed to radioactive rays. Therefore, you can only undergo this procedure a number of times. Even this small amount of radiation might cause some complications. It could even increase the chance of developing cancer in fast-growing cells, for example, the cells of fetuses. If you're pregnant or you may be pregnant, you should not get a PET-scan.
Because the radioactive material is combined with glucose, it can be a concern for some diabetics. They can only undergo a PET-scan with certain precaution.

Even though the PET-scan is extremely precise, there is always a chance of getting a false negative result. Some tumours don't 'absorb' the isotope for example or sometimes the isotope can't reach specific parts of the body

The last disadvantage is its high initial cost and ongoing operating costs. It's covered by your health insurance, nevertheless it's a very expensive treatment.

Who invented it?

Edward Hoffman and Michael Phelps developed the first Positron Emission Tomography scanner for human studies in 1973. The first whole-body PET scanner appeared in 1977. At the time, Hoffman was working at Washington University, the same place where he earned his doctorate in nuclear chemistry. Phelps and Hoffman won the Medical Imaging Scientist Award from the Institute of Electrical and Electronics Engineers. Phelps also received the 1998 Enrico Fermi Presidential Award for his work. Their invention has made a big difference in the medical world. Today, there are 2500 units in the US alone. So you can only imagine how many there are worldwide.

How does the clinical visit proceed?

As a preparation for the scan, you'll probably be asked to refrain from strenuous physical activity for two days and to stick to a low-carbohydrate, no sugar diet. The patient shouldn't have eaten for six hours before the scan.

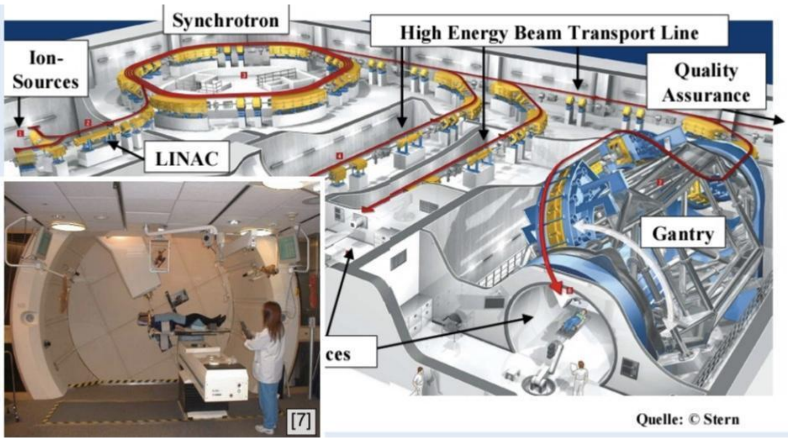
When you arrive at the nuclear medicine department, they'll start the procedure by measuring your blood sugar level. You'll get a low dose of radioactive glucose and half a litre of moisture, most probably intravenously. You'll have to wait at least an hour before the substance has spread across your whole body. It is important to rest while the glucose works in, to minimize the energy consumption of your muscles. The intention of this is to avoid the absorption of the glucose by your muscles, the radioactive substance should instead be absorbed by the active malignant cells. In the meantime, you'll get a second injection that'll stimulate your bladder. Your bladder should be empty.

During the scan, you'll lay on an examination table. The PET-scanner is a large machine that looks like a giant doughnut, it has similarities with a CT-scanner (medical imaging technique that uses multiple X-ray measurements to produce images). The duration depends on which type of scanner is used and which body parts are being scanned.

After the PET-scan you can just drive home and you may eat and drink again. You should avoid being close pregnant women and young children for 24 hours after the scan. Normally you won't have any side effects.

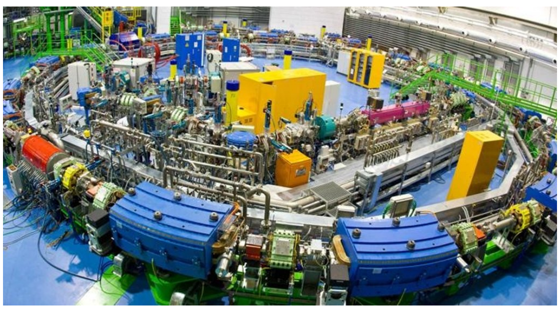
HADRON THERAPY

Hadron therapy is a type of radiation therapy, a way to treat cancer with ionizing radiations. Usually, the radiation therapy irradiates the tumour, but some radiations always settle in the healthy tissues. With the Hadron therapy, the damage to healthy tissues is less.



How does Hadron Therapy work?

Hadron therapy uses beams of energetic neutrons, protons, carbon ions and hadrons. Hadrons are subatomic particles made up of quarks, which are the constituents of neutrons and protons. There are six different types of quarks, the most common are the quark up and down. Hadrons are more massive than electrons and can therefore depose more energy to the tissue, so they are more effective. Through a cyclotron or a synchrotron, hadrons are accelerated to reach the necessary energy to kill the tumour. The synchrotron is a medical device that has a ring shape, with two ion sources, where the particle beams are created. Here, atoms that have lost their electrons are extracted, then protons or carbon ions are selected by magnetic fields. The beam is accelerated and brought to the synchrotron, as shown in the photo (blue parts are magnets. Then the beam is sent to the treatment rooms and hit the cancer cells. The DNA of their nucleus is damaged and when cells die, they are eliminated by the immune system. Beams have different ranges of effectiveness, the Bragg peak is the point of major effectiveness, so different types of subatomic particles have a different Bragg peak. This can be useful for tumours at different depths and dimensions, for example, electrons are used for superficial tumours, while protons and heavier ions reach a greater depth. Beyond the Bragg peak, the dose is almost zero.



Advantages and disadvantages

Advantages:

- This therapy can treat tumours that are near vital organs or children, who need more attention because their developing structures need to be preserved;
- It can be applied to a wide range of tumours and the treatment is matched to their size;
- It has a low radiation risk, the patient is exposed to less radiation;
- People can maintain their lifestyle and also their employment.

Disadvantages:

- There are no studies which compare it to traditional therapy;
- Everyone has different necessities and nowadays the data are still a few;
- There could be side effects after the therapy.

Who invented it?

The physicist Robert Wilson in 1946 had the idea to use protons for cancer treatments, in the 1950s there were the first applications, but only a few parts of the body were accessible, because accelerators were not powerful enough, so protons could not penetrate deep.
Later, thanks to improvements in accelerator technology, in the 1990s this technology became a good option and some centres were opened.
Nowadays, this therapy is used for the treatment of tumours that do not respond to the traditional ones, or for tumours located in sensitive parts of the body, for instance, the ones of the base of the skull.

How does the clinical visit proceed?

First of all, to have access to Hadron therapy the patient and the doctors need to understand if the pathology can be treated or not. If after a first evaluation the patient's case results treatable, he or she needs to deal with bureaucracy and wait two weeks to receive the final result of the second deeper evaluation. If the patient has a possibility of access to therapy, he or she is subject to a first outpatient visit. Before taking preliminary tests and starting the personalised treatment, a multidisciplinary evaluation that lasts two weeks takes place, in which the medical staff prepares the treatment and sets the visit schedule.
Hadron therapy takes place in specific centres with a very big place because all the equipment and treatment need a lot of space. In fact, in hospitals, the Hadron therapy units are larger even than the X-ray therapy units.
When a patient is subjected to Hadron therapy he or she needs to be alone in a room which is connected to another room where particles are accelerated. The medical staff need to be isolated from the patient's room and from the room which contains the hadron equipment.
During the therapy, the patient needs to be monitored in a very strict way, because little aspects such as changes in weight, fitness and lifestyle, injury, pregnancy and fast growth rates can seriously damage the development of the therapy. Before going in, the patient needs to be checked to control the state of the tumour. Usually, the timing for the therapy depends on the particle that is used: carbon ions need to be administered for four days a week up to four weeks; protons need to be administered five days a week for at least seven weeks. As it is shown in the picture, the patient is subjected to every session for thirty minutes, which is the average timing of each session. When the patient is subject directly to the therapy any voluntary or involuntary movements can happen, but this doesn't have bad consequences.

Hadron therapy is not very common, all over the world 28 centres use Hadron therapy, most of them are located in the US and Japan. There are also a few centres in Europe, in particular in Germany; but Italy also hosts two very important centres, in Pavia and Trento.

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