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ORIGINAL PAPERS

Proton Therapy – Medical Procedure in Oncological Therapy

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Abstract
The paper presents proton therapy as a method of treating cancer, the action of proton therapy, the proton as a subatomic particle that can controlled to obtain and deliver radiation directed to tumors and radioactivity. A comparison is made between proton therapy and X-ray radiation, pencil beam scanning technology is presented, treatment with proton therapy, advantages and disadvantages of proton therapy and it finishes with a conclusion and a bibliography.

Keywords*:* proton therapy, radioactivity, proton, medical procedure, cancer

Introduction - History of Proton Therapy

British physicist Ernest Rutherford demonstrated the existence of protons in 1919 and physicist Robert Wilson proposed protons to be used to deliver an increased dose of radiation to a tumour, simultaneously reducing the exposure of surrounding healthy tissue to radiation in 1946. The first research studies were conducted on patients in the US and Europe. Advances in imaging technology, including CT, MRI and PET scans, helped researchers better diagnose and detect tumors, making proton therapy a more practical treatment option in the 1980s. The first patient received proton treatment more than 50 years ago, and the US Food and Drug Administration approved proton therapy as a radiation treatment option in 1988. To date, more than 180,000 people worldwide have received proton therapy at cancer centres in Europe, Asia and the United States.

Advances in imaging, CT, MRI and PET scans now allow doctors to pinpoint and precisely define the location, size and shape of tumours. This capability, combined with improvements in proton technology, has led to today's increased interest in proton therapy as an important treatment option for cancer. Worldwide, there are approximately 30 centres where nearly 70,000 patients have been successfully treated. The goal of research in this area is to develop smaller, more compact accelerators that have a smaller cost so that they can be built and used in greater numbers to treat patients who need them.

Röntgen rays discovered in 1895 have been used for therapeutic purposes. The newest method of radiotherapy is proton irradiation which seems to be more effective and have fewer complications. Proton radiation can be directed at the tumour three-dimensionally, with millimetre precision, and the distance of penetration into the biological tissue can be controlled. In this way, healthy tissue behind the cancerous region will not be irradiated and thus highly sensitive organs can be protected.

Proton therapy is an extremely precise and much less invasive form of cancer treatment. Protons are positively charged subatomic particles that can be manipulated and controlled to stop and deliver radiation directly to a tumour, travelling no further than the outer wall of the tumour. Proton therapy effectively targets cancer and reduces the risk of serious side effects.

Proton therapy is an innovative way of treating cancer that delivers radiation at precise depths to precisely target tumours. Much of the radiation is deposited exactly at the site of the tumour and then stopped, reducing excess radiation to healthy tissue. Like X-ray radiation, proton therapy destroys cancer cells by preventing them from dividing and growing. But unlike the photons used in X-ray radiotherapy, proton therapy uses positively charged atomic particles - known as protons - to target cancer cells with greater precision and no exit dose.With proton therapy, a higher dose of radiation can be delivered to the surface of the tumour, while reducing exposure to surrounding organs and healthy tissue.

Proton therapy or proton therapy is an advanced type of radiotherapy used to treat certain types of cancer. The precise delivery of radiation to the tumour site means there is less risk of damage to surrounding healthy tissue.

Proton therapy uses accelerated subatomic particles - protons - to treat a variety of cancers and certain non-cancerous tumours. Unlike other types of radiotherapy that use radiation to destroy cancer cells, proton therapy uses a beam of special particles called protons. Doctors can better target the proton beams to a tumour, so there is less damage to surrounding healthy tissue.

The proton is a component part of the nucleus of an atom and a positive electric charge. The number of protons in an atom is equal to the atomic number of that element. Radioactive decay of free neutrons can produce protons, electrons and antineutrinos. The number of neutrons defines the isotope of the element. Atoms with the same number of protons but different numbers of neutrons are different isotopes of the same element. All known isotopes of elements with atomic numbers greater than 82 are radioactive. The stability of isotopes is affected by the ratio of protons to neutrons. Each element has one or more isotopes with unstable nuclei that are subject to radioactive decay, causing the nucleus to emit particles or electromagnetic radiation.

Proton radiation is a form of external beam radiation treatment, delivered by generating a beam that enters the body from outside. When protons interact with electrons in the atoms of cancer cells, they transmit energy that damages the cancer cell. This destroys the specific functions of the cells, including their ability to divide or proliferate. As a result, the cancer cells die and so does the tumour.

Proton therapy is performed on an outpatient basis. The treatment lasts a few minutes a day for 6 to 7 weeks, depending on the type of cancer.

Last year, the high-power laser system at the Extrem Light Infrastructure - Nuclear Physics Romania Centre reached 10 PetaWatts, the world's largest nuclear physics ELI-NP, built at Magurele in the premises of the Institute for Nuclear Physics and Engineering - Horia Hulubei. This system could replace existing accelerators, including the production of accelerators for cancer therapy through proton therapy, which has the ability to destroy the cancerous tumour without damaging the surrounding tissue.

In addition to surgery and chemotherapy, tumours are usually treated with various types of radiation (radiotherapy) to destroy cancer cells. Most often, gamma radiation (photons) from the decay of a radioactive source of Cobalt-60 is used and sometimes beta radiation (electrons) is used. These particles are absorbed all the way to the tumour area, thus affecting not only the diseased region but also the healthy tissues in the tumour area. It is obvious that in the case of tumours located in vital areas - such as the brain or the eye - this method can have, in addition to positive effects, negative effects which can endanger the functioning of the organs concerned and, therefore, the life of the patient.

Proton therapy is a highly selective form of radiotherapy, which has the advantage of additional protection of the tissues around the tumour compared to X-ray radiotherapy.

Photon radiation typically uses multiple X-ray beams to attack a tumour target, but inevitably the radiation reaches healthy tissues beyond the target, potentially damaging those tissues as the beam leaves the body.

Radioactivity

Studies of the effects of ionising radiation became necessary after the introduction of X-rays in medical therapy and diagnosis at the beginning of the 20th century, and have gained great relevance in the nuclear age. Thus, in addition to X-ray machines which allow X-rays of various organs of the body to be taken, new techniques such as positron emission tomography and hadrontherapy have been developed. Radiation is defined as a beam of moving particles. The term particle is used in the most general sense and includes both particles with non-zero rest mass and particles with zero rest mass. For example, the first category includes alpha and beta radiation and the second category includes X and gamma radiation. Radioactivity is the property of some nuclei to spontaneously emit radiation. The nucleus is said to disintegrate.

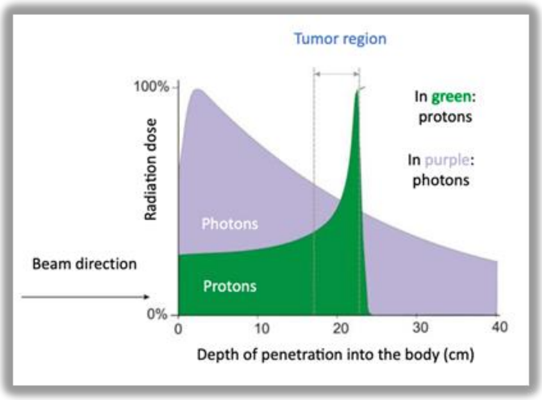
Two sizes mainly characterise a radioactive nucleus:

- Activity A which represents the number of disintegrations a source undergoes (amount of radioactive material) per unit time;
- The half-life is the time after which the activity of a source decreases by half.

In radiotherapy, cancerous tissue is irradiated with gamma radiation produced by isotopes that emit this radiation with very high energy, such as caesium and cobalt. Tractors are radioisotopes that are attached to proteins, nucleic acids and other components in cells. By measuring the radiation emitted, it is possible to track its movement in the body. In the case of indoor irradiation, certain alpha-emitting nuclides are introduced into diseased cells, which they irradiate and destroy. The most common forms of radioactive decay are alpha, beta and gamma decay.

The proton, made up of three quarks, is an electrically positively charged particle, about 1836 times heavier than the electron, whose energy loss when passing through living tissue can be controlled by the energy level of the beams. Basically, what happens is this: protons accelerated to a certain energy are directed towards the tumour, enter the patient's body and pass through it with very little damage to healthy tissue; once they reach the tumour they transfer almost all their energy to the tissue, triggering processes that destroy cancer cells and prevent them from multiplying. Healthy tissues remain virtually unaffected by the radiation, while diseased tissues are destroyed. The higher the energy of the beam, the more proton energy is released into deeper tissues. For superficial tumours, protons with lower energies than those used to treat tumours deeper in the body are used.

The graph below shows how protons give up energy differently to living tissue compared to photons. Purple shows the photon energy transfer curve - it is clear that energy is transferred to living tissue throughout; green shows the energy transferred by protons; a maximum (a peak value) of energy transfer is seen, which can be directed to where the tumour is located.



Pencil beam scanning technology

Pencil Beam Scanning is a revolutionary technology that improves accuracy with its ultra-sharp proton radiation beam. Pencil Beam scans the tumor with radiation in three dimensions by moving a proton beam with the sharpness of the pencil point back and forth across each layer of the tumor. This extreme precision allows the radiation dose to conform to the specific shape and size of the tumour, making it ideal for irregularly shaped tumours near critical organs and tissues. The latest proton therapy technology, pencil beam scanning allows a precise dose of proton therapy to be delivered to a tumour. The technology limits radiation exposure to surrounding tissue. Pencil beam can be used to treat cancerous and non-cancerous solid and complex tumours in adult and paediatric patients.

Comparison of proton therapy and X-ray radiation

X-ray radiation and proton radiation are types of 'external beam' radiotherapy used to treat different types of cancer. However, the properties of each are very different and result in different levels of radiation exposure.

Proton therapy and X-radiation are types of radiotherapy that destroy cancer cells by preventing them from dividing and growing. The difference, however, is in their delivery: protons are subatomic particles that can be controlled to deliver their radiation at precise depths and much of their radiation is deposited exactly at the tumour site and then stops, whereas X-rays release radiation from the moment they penetrate the skin to the other side of the tumour.

Pencil beam radiotherapy involves:

- Protons enter the body and deposit only a small dose along the way to the target and virtually none beyond;

- The absorbed dose gradually increases with higher dose and slower speed until the beam reaches the Bragg peak - the point at which maximum energy is deposited - which is directed exactly inside the tumour;
- Immediately after this burst of energy, the proton beam stops completely and any further radiation ceases.

This is highlighted in the image below:

Treatment in proton therapy

Proton therapy is a non-invasive and painless treatment, during which patients feel no physical sensation from the proton beam, hear very little noise and experience minimal discomfort. Unlike older technology, each treatment session lasts about 30 minutes, with actual treatment time lasting only 1 to 3 minutes. Full two-way video and audio allow medical team members and patients to communicate throughout the entire process.

The device used in proton therapy is a system that rotates around the body, which sits on a table and slowly slides into the circular opening of the machine. This system rotates around the body to direct the proton beams to precise points on the body. Proton therapy is delivered by a device called a cyclotron, which sends a high-energy beam of protons through the skin to the tumour. Computer programs are used to calculate how to deliver the treatment at the exact dose and location.

After the treatment session is completed, the body is not radioactive and does not emit radiation. Radiation side effects usually develop over time. It is possible that some side effects may occur at first.

The treatment protocol provides for an initial phase of several days, optimising the energy and beam orientation according to the tumour to be treated, after which 12 to 16 sessions of several minutes are carried out (the number varies, depending on the tumour to be treated). A particle accelerator is needed to apply this treatment method, which makes it much more expensive than methods using photons (X-rays or gamma rays) or chemotherapy.

Proton therapy can cause side effects as cancer cells die or when the energy in the proton beam affects healthy tissue.In general, common side effects of proton therapy include: fatigue, digestive problems, headaches, hair loss in the treated body region, reddening of the skin in the treated region.

Proton therapy - treatment of various tumours

Proton therapy is most commonly used to shrink solid tumours that have not spread to other parts of the body. It is often the preferred option for treating solid tumours in children, as protons can be controlled so that there is less damage to normal tissue, helping to prevent serious complications and reduce the risk of secondary tumours. It is an effective treatment for many types of cancers in children, including:

- brain tumours;
- sarcomas (cancers that grow in connective tissue);
- tumours of the head, neck, eyes and spinal cord;
- lymphomas (cancers affecting the lymph nodes).

Proton therapy is sometimes used in conjunction with other cancer treatments, such as standard radiotherapy, chemotherapy, surgery and immunotherapy. But the therapy can be used for many cancers: abdominal and gastrointestinal cancer, anal cancer, biliary tumours, brain tumours, breast cancer, oesophageal cancer, gastric cancer, head and neck cancer, liver cancer, lung cancer, lymphoma, pancreatic cancer, prostate cancer, rectal cancer or cancers that have recurred. In addition to cancer, proton therapy has been effectively used to treat Parkinson's disease, epilepsy, macular degeneration, arteriovenous malformations, severe rheumatological conditions.

The advantages and disadvantages of proton therapy are:

- Ultra-precise, less invasive technique with minimal side effects, proton therapy is an effective treatment for both children and adults.
- Radiation is delivered directly into the tumor and is stopped, maximizing the dosage of cancer cells and minimizing damage to healthy tissue.
- With no exit dose, surrounding healthy tissues and organs are spared radiation. Both short-term and long-term side effects are minimised.
- The ultra-precision of proton therapy makes it ideal for even the most complex cases. Irregularly shaped, hard-to-reach tumours close to vital organs or recurrent after previous treatment can be targeted with the highest accuracy. Proton therapy reduces the risk of secondary tumours compared to conventional X-ray radiotherapy.
- Protons can be manipulated to stop and deliver radiation directly to a tumour rather than further away.
- Proton therapy allows doctors to vary the intensity of the radiation dose at any point in the tumour, which has not been possible with other technologies.

- Reduced radiation toxicity leads to a lower incidence of secondary tumours compared to standard X-ray radiation and has fast treatment times

Protons release their maximum energy at the end of the trajectory set by the doctor and the depth of penetration of ionising energy is predetermined and has sub-millimetre precision. Beyond the tumour there is no more exposure, no more absorption of ionising radiation, so healthy tissue is spared and tissues lateral to the tumour are not affected. This means that adverse effects are reduced and the risk of a second cancer developing after radiotherapy treatment is reduced.

Proton therapy is not suitable for all cancers, but is recommended for brain tumours, tumours located in the spine, prostate cancer, head and neck tumours or lymphomas located near vital structures sensitive to irradiation. The method, called proton therapy, uses equipment and technologies that come directly from nuclear physics laboratories.

Basically, what happens is this: protons accelerated to a certain energy are directed at the patient, enter the patient's body, where they can travel with very little damage to healthy tissues, and reach the tumour where they deposit almost all their energy, which destroys the tumour by breaking/damaging the atomic nuclei of the cancerous tissues. The treatment protocol includes an initial phase of a few days to optimise the energy and target the beams to the tumour to be treated.

Conclusions

Proton therapy is a highly effective method of treating tumours with proton beams from dedicated particle accelerators. Currently, the aim of research in this field is to develop smaller and more compact accelerators that cost less so that they can be built and used in greater numbers to treat patients.

Energy-rich proton irradiation is considered in the medical world to be the most modern form of malignant tumour control.

The therapeutic virtues of proton irradiation in fighting cancer have been known for decades, but it is only now that doctors will have the technique to apply it.

Proton beam therapy will be particularly useful for patients who have not been able to benefit from roentgen irradiation. These include deep tumours, for example in the bone marrow or lungs, or in highly sensitive areas such as the eye or ear.

Irradiation is done with millimetre precision, thus protecting the tissues around the tumour. Protons are accelerated in electromagnetic fields at 60% the speed of light. When precisely directed, they discharge maximum energy directly into the tumour. Beyond this, no further irradiation is discharged. The proton destruction of malignant cells is three-dimensional in the tumour and is incomparably greater than with conventional roentgen or linear accelerator photon radiation.

By using high doses of proton irradiation, the life expectancy of patients is prolonged and their quality of life is greatly improved, precisely because the destruction of diseased tissue is done while protecting healthy tissue. There is as yet no experience with proton irradiation treatment of metastases. Specialists hope that the method can be applied with good results here too.

The applications of fundamental physics in everyday life are becoming increasingly important and present in society, contributing substantially to improving the quality of life.

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