COMPARING IONIZING RADIATION THERAPY
AND CHARGED PARTICLE RADIOTHERAPY

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When a person is diagnosed with cancer, the typical treatment of the malignant tumor involves surgery, chemotherapy and radiation therapy. Conventional radiation therapy uses ionizing radiation (such as X-rays or gamma radiation) aimed directly at the tumor. This damages the DNA of the cancerous tissue, triggers complex biochemical reactions in the tumor and can through repeated treatments eventually result in cellular death. [1]

The ionizing radiation, however, also damages healthy tissue, making the treatment of tumors close to critical body structures (e.g. the spinal cord or the brain) very dangerous or nearly impossible.

The cancer therapy treatment center MedAustron in Wiener Neustadt (Austria) is currently (as of 2014) in its technical test phase. When treatments begin in 2015, it will use both proton and carbon ion beams for so-called charged particle radiotherapy instead of conventional ionizing radiation. It will be the first and so far only such facility in Austria.

After introducing the basic concepts of radiation therapy, it will be shown that the use of proton or ion beams has important advantages over conventional types of radiation therapy and that it can be applied to areas of the body where the use of X-rays would risk damaging vital organs or other critical body structures.

In order for the selected particles to reach the energy levels necessary for use in therapy, a particle accelerator is needed. The basic operating principle of the synchrotron type particle accelerator in use at the MedAustron facility will be briefly explained.

Finally, the MedAustron facility itself will be discussed, particularly as regards the treatment of patients.

Conventional radiation therapy as it is generally used nowadays in cancer treatment typically employs electromagnetic waves with short wavelengths (like X-rays or gamma radiation) and a sufficiently energy level, so as to be capable of ionizing atoms or molecules. Hence the term “ionizing radiation”.

The amount of energy that ionizing radiation deposits to a specific volume of tissue is called “(absorbed) radiation dose” and is measured in Gray units (Gy). Cellular damage increases with the absorbed radiation dose. [1]

However, this ionization of atoms or molecules happens in diseased as well as in healthy tissue. Exposure of healthy, living tissue to certain doses of radiation may result in mutation, radiation burns, cancer or, in extreme cases, even death. Still, when applied to the very specific area of a tumor, with exact targeting and appropriate dosage, cancerous cells can be eliminated with minimal damage to surrounding healthy tissue. Nonetheless, when a tumor is close to critical body structures such as the brain or the spinal cord, even minimal exposure of surrounding tissue to radiation may cause significant and even irreparable damage. [2]

This negative effect can be alleviated in certain cases by targeting the tumor from different angles, to avoid overexposing the same healthy tissue and by breaking the total dose of radiation into smaller portions over successive sessions. This in particular allows the healthy tissue to recover from any damage due to irradiation, while still continuously increasing the damage to the cancerous cells. [1]

An alternative form of radiation therapy is the so-called charged particle radiotherapy, using protons, helium, carbon, neon, silicon ions or other charged particles. These particles have certain properties that allow for a much more exact targeting of the cancerous tissue, significantly decreasing the exposure of the surrounding area. This results in fewer negative side effects and the possibility of delivering higher dosages to the desired area, therefore possibly decreasing the number of treatments necessary.

The advantages of a more exact targeting are clear: areas which with conventional radiation therapy would have been too dangerous to
irradiate because of their proximity to vital organs can now be treated using charged particles. Tumors which previously could not have been treated using conventional methods can now be treated efficiently and with a bare minimum of side effects through ion beam therapy.

With ions a tumor can be treated at any depth inside the body, with a minimum dose of radiation to the surrounding healthy tissue. This is possible, because the penetration depth of the ions can be regulated by their initial energy and therefore be directed to deliver the necessary radiation to a specific area inside the tumor. [3]

*Figure 1* illustrates a specific property of charged particles, namely the different depth/dose distributions compared to photons (such as X-rays). Most of the energy of charged particles is deposited at the very end of their trajectory, when their speed decreases. This decrease in speed results in a localized peak of dose, called the Bragg peak, which can be programmed to occur precisely at a specific point inside the tumor. The penetration depth, which is the depth at which the Bragg peak will occur, is determined by the initial energy of the particle, the applied dose of radiation is determined by the intensity of the beam. The adjustments of both particle energy and beam intensity can be accomplished with high precision. In order to irradiate an entire tumor, multiple Bragg peaks of various particle energies and beam intensities (called “pristine” peaks) are combined, forming a so-called “spread-out Bragg peak” (SOBP). The width of this combination of peaks can be adjusted by the number of “pristine” peaks, according to the size and shape of the tumor.

Additionally, one of the most important advantages the charged particle therapy has over conventional radiation therapy also becomes evident in *figure 1*. As can be seen very clearly, the photon enters the healthy tissue at its highest energy level and only gradually decreases as it passes through the tumor, therefore irradiating a large area surrounding the tumor.

The spread-out Bragg peak on the other hand not only has a significantly lower energy level at the beginning and deposits the bulk of its dose inside the tumor, it delivers nearly no dose at all beyond the tumor position of 150 mm. This is a considerable advantage when dealing, for example, with a tumor near the spinal cord. [1]

In the case of the *MedAustron* facility, the necessary kinetic energies of the charged particles range from 60 to 250 MeV for proton beams and from 120 to 400 MeV per nucleon for carbon ion
beams. Typical penetration depths for both types of beams range from 35 to 275 mm. [4]

In order for charged particles to reach such high energies, a particle accelerator is needed. The MedAustron facility is equipped with a synchrotron type accelerator, designed and constructed in collaboration with the European Organization for Nuclear Research (CERN). [5]

As Figure 2 shows, the particles from the ion source are first accelerated through a linear accelerator (LINAC), before they are sent onward to the actual synchrotron. The LINAC accelerates the ions to the synchrotron injection energy of 7 MeV per nucleon. The synchrotron itself houses a variety of dipole, quadrupole and sextupole magnets required for accelerating, bending and focusing the particle beam. When the particle beam has reached the necessary energy level (as described above), it is extracted and directed towards the treatment rooms.

In addition to medical treatment rooms, a laboratory facility is also available for research in the fields of medical radiation physics, radiation biology and experimental physics. [5]

Patient treatment is set to start in 2015, with three treatment rooms available. The capacity of the therapy center is expected to reach around 1200 to 1500 patients annually. [4]

With continuing, successful research in the field of radiation therapy and especially charged particle therapy, many new facilities around the world are being commissioned or are already currently under construction, making it possible for many patients to be treated more efficiently and significantly minimizing the involved risk.