Two Experts Tell the History and Benefits of Beam Scanning

Only two institutions worldwide use beam scanning as a method to direct the beam exactly to the malignant tissue: the Paul Scherrer Institute (PSI) in Villigen, Switzerland, and the 'Gesellschaft für Schwerionenforschung' (GSI) in Darmstadt, Germany. Eros Pedroni, Ph.D., from PSI, and Thomas Haberer, Ph.D., from GSI, explain what makes this method so remarkable and what further developments can be expected.

MEDICAL SOLUTIONS: How did you get the idea of using beam scanning in the first place?

PEDRONI: Basically, the idea of beam scanning originated in 1980, when we started using pionic therapy at PSI. That was also when we started inverse planning with pions. Intensive pion research had been conducted since 1973 at PSI when an accelerator was built specifically for fundamental research in elementary particle physics. The idea to use pions in radiation therapy is based on their high LET characteristics and their property of reaching their highest effect exactly at the focus point. We started with a simple horizontal beam, but were not satisfied with the dose rate. Using a pion applicator, the so-called Piotron, equipped with supraconductive technology, we were able to accumulate 60 concentric beams in one focal point. Therapy planning with a CT, in fact, was also contemplated for the first time as soon as 1980. We had one of the first systems which used a CT for therapy planning. Actually, beam application in pionic therapy was a form of spot scanning from the very beginning. The pion focal point formed a hot spot, where high LET effects were produced. The patient was positioned in a water bolus and was moved on a trajectory in three dimensions to perform conformal therapy with the hot spot. But the pion focus point was as large as 5 to 6 cm in diameter and therefore mainly large pelvic tumors or sarcomas could be treated with this method. Nevertheless, from 1980 until 1992, about 500 patients were successfully treated with pions.

Many experiences and concepts, such as therapy planning, patient positioning, and the design of the control systems, could be implemented into the proton therapy research. Beam scanning was one of these concepts. Today we know that high LET treatment works best with carbon ions.

HABERER: We wanted to develop a method to reach a conformal dose distribution by precisely directing highly efficient ions into the target volume. A precondition for the beam scanning method was the overall development of the accelerator technology. By the end of the '80s, we were able to vary the beam energy very quickly, which then again enabled us to direct a high-quality beam into each target volume. Ion interaction with tissue, particularly in the entrance channel, needs to be considered in order to include biologic effectiveness into therapy planning and the treatment itself. If we really want to accurately cover the malignancy and spare as much nonmalignant tissue as possible, then the only alternative is beam scanning. Hybrid methods, such as scanning combined with passive energy variation or purely passive beam application, are always a compromise with respect to dose quality and distribution.

With beam scanning, we are able to actively position the Bragg peak in three dimensions into small volumetric elements. An adequate planning system is necessary to take all physical and biological dose effects into account. That's why the development of the planning system was linked closely to the development of beam scanning and accelerator technology.

MEDICAL SOLUTIONS: What can you tell us about beam scanning and the development of a monitoring system?

HABERER: In 1990, our Synchrotron system produced the first beam. One year later, we scanned the letters "GSI" for the first time, with only one dose rate, but nevertheless with a focused, pencil-shaped beam. GSI's biophysics department developed the first control system for the scanner prototype. By 1996, we had a range library, which allowed millimeter resolution in a water phantom. The monitoring system was being developed at the same time. Basically we had the situation that in our physical experiments we were already using detectors that could accurately detect dose intensity with a relatively high temporal resolution, as well as multiwire chambers to measure width and location of the beam. But these detectors could not be read out fast enough to entirely track the scanned beam. Finally, in 1994, we managed to actually track a beam with a traveling speed of 10 m/s. The fast monitoring of the beam position is an absolute prerequisite to fulfill the safety requirements in radiation therapy with beam scanning.

PEDRONI: In 1984, we started the treatment of eye melanomas at PSI. We used a special horizontal proton beam with conventional scattering technology for this purpose. Up to now, about 4 200 patients have been treated with excellent results.

These positive experiences motivated us to apply proton therapy to deep-seated tumors as well. We started using proton beams, which were originally installed for experiments with polarized protons and neutrons. The PSI accelerator has a maximum energy of 590 MeV, which is too high for this kind of therapy. We reduce the energy down to 100 to 200 MeV with a degrader. Scanning was initially tested with a horizontal beam. At the same time, a gantry was planned and completed in 1992. Everything related to the beam – control systems, dosimetry, therapy planning, and positioning – was developed by PSI. The mechanical parts were purchased at a company called Schär Engineering.

Over the years, we were able to continuously improve the technology using numerous radiobiological and dosimetric experiments as well as conclusions from treatments of animal

UNTIL 2005, Thomas Haberer, Ph.D., was the technical project manager for heavy ion therapy at GSI, Darmstadt, Germany. Since July 2005, he has been scientific-technical director for the Heidelberg-based Ion Beam Therapy Center.

patients. The first patient was treated in 1996. We immobilize the patients and perform the patient positioning with a CT outside of the treatment room. Today, in most cases, patient positioning is verified with a CT outside of the treatment room. The spot-scanning technology that we introduced has greatly interested our colleagues and has now turned into a method to treat patients accurately without collimators and patient-specific boluses.

Over 200 patients – mainly with tumors in the head, spine, and pelvis, but only tumors that cannot move during therapy – have been treated since 1996. By integrating anesthesia into the treatment rooms, we can now also treat pediatric patients, who in particular benefit from the precise radiation application of the proton therapy with the help of beam scanning.

MEDICAL SOLUTIONS: Why don't more institutes put beam scanning into practice?

HABERER: I believe that the complexity of the method evokes a lot of scepticism. The accelerator system has to be very flexible, reliable, and precise to accurately cover 250 energies times 7 focus settings times 15 intensity levels. This can only be accomplished by state-of-the-art accelerators. There are also concerns regarding the precision and reliability of the method as well as the accuracy of dose distribution that was created with a beam with a resolution of as low as a couple of millimeters. We were able to dispel these concerns with the help of many experiments with phantoms and animal models and with the help of PET measurements. I think we are on the right track, since more and more recent projects are calling for beam scanning.

MEDICAL SOLUTIONS: The installation of a second gantry is planned at PSI, especially for clinical applications...

PEDRONI: We will start using a second gantry at PSI for tumor treatment and we will expand our current capabilities and experiences even further. To make scanning faster is one of our main goals.

Today, with magnetic steering, we can only direct the beam into one direction, while to steer it into the other, the lateral direction, we actually move the table. With the new gantry, we will be able to magnetically deflect beams in both transverse dimensions and encompass a field of 12 by 20 cm. We will additionally stick to the established table movement that allows us to perform treatments in the cranio-spinal axis with only one beam field. We can reach a field size of 80 cm with parallel beam scanning and the mobile table.

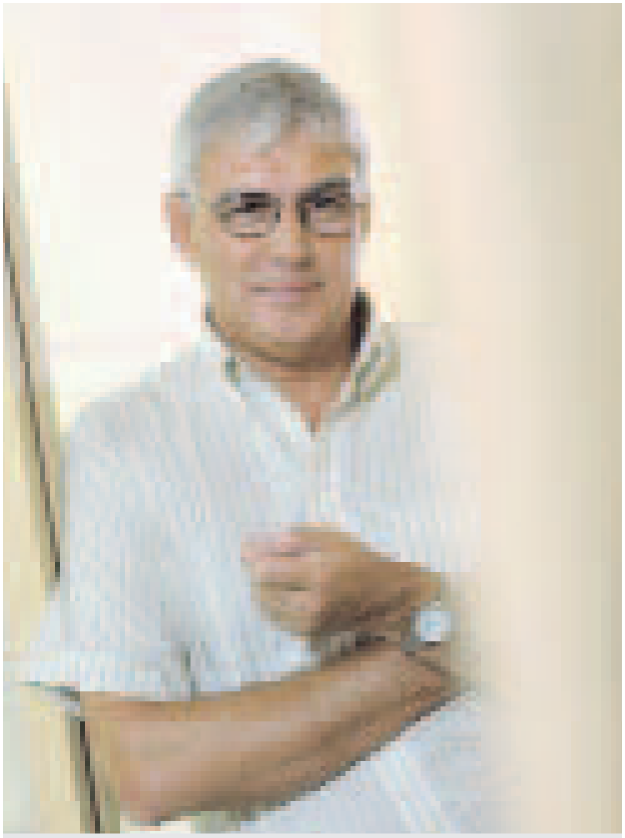
MEDICAL SOLUTIONS: Which fields of research can be expected for proton therapy and beam scanning in the next few years?

PEDRONI: The greatest clinical advances that we expect from proton therapy with spot scanning are in intensity-modulated proton therapy (IMPT) and the treatment of moving tumors. With the new gantry at PSI, we will be able to move forward in both fields of research.

HABERER: As mentioned before, a major research field in beam scanning is its application to moving organs. Therapy planning based on a time-resolved diagnosis, real-time monitoring during treatment, and online adaption of the beam position are the three main components. We are working hard on this topic to expand the treatment spectrum of particle therapy.

We are continuously improving our technologies. When it comes to detectors, for example, we are thinking about different concepts that are based on semiconductor technology and are easier to assemble. We are looking for time advantages in our technique to make scanning faster and more precise. This would mean shorter treatment duration, which in the end would benefit the patient most of all. There is still so much potential and flexibility in beam scanning, even when treating motionless tumors. The more information clinicians can give us about the development of the tumor regarding shape, size, and biologic sensitivity during treatment, the better we can optimize dose distribution. With adequate clinical information, we can treat each patient individually, and we can tap the scanner's full potential, which is by no means exhausted yet.

The information about this technique is preliminary. The technique is under development and is not commercially available in the U.S., and its future availability cannot be ensured.



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