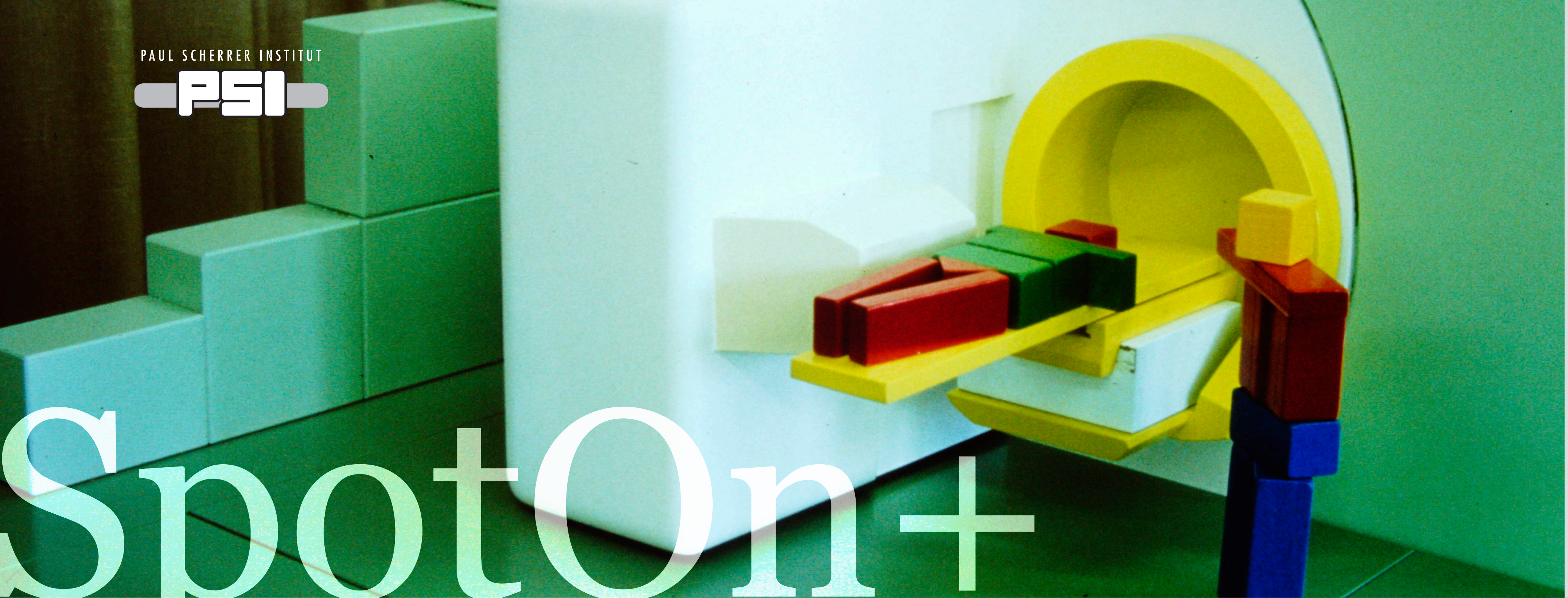
PAUL SCHERRER INSTITUT



SpotOn+

Center for Proton Therapy :: Paul Scherrer Institut :: #10_12/2016

Dear Colleagues

This winter's edition of our SpotOn+ newsletter is dedicated to the 20th anniversary of the Gantry 1 (G1), which treated on November 25th 1996 a patient with a recurrent brain metastasis. G1 was the first PBS Gantry in the world and due to the non-isocentric design, remains one of the most compact gantry with a minor foot-print signature. Above is a picture taken 25 years ago of a Tinker toy-model of G1 to fully understand the mechanism and limitation of such a piece of hardware. Sometimes, scientists need to leave the drawing board and play with models in order to better visualize the Gantry movements… PSI is not only a facility with 'big toys for boys' but physicists can also play with smaller scaled toys… This gantry has treated successfully over a 1'000 patients with no technical defect in these two decades of operations. This shows the know-how of PSI in blue-printing, constructing and operating Gantries, the former being applied to the second-PBS generation of Gantry, namely Gantry 2 (G2). Dr Psoroulas details the advantage of line-scanning, when compared to spot scanning, using G2 for the delivery of treatment for static or mobile tumors. In line scanning, the dose is adjusted by the actual speed of the scanning process (in essence it is a time driven delivery) and this delivery paradigm enables one to minimize the dead time (e.g. from spot to spot). Additionally, another magnitude of modulation is given by the active control of the beam intensity from the COMET cyclotron (Varian Medical systems, Troisdorf, D) which will reduce further the delivered dose at maximum scanning speed by decreasing the beam current extracted from the ion-source. The advantage of line scanning is bigger when using a motion mitigation strategy such as rescanning. To deliver 10 rescans for 2 Gy delivered to a one liter target volume, 5 and 1.5 minutes would be needed with spot- and line-scanning, respectively. Finally, the water-equivalent path lengths (WEPLs) to the distal edge of the treatment volumes were analyzed by one of our PhD Ms Gorgisyan. The delta (Δ) of WEPLs were calculated on 2 breath hold CT scans of lung cancer patients. A higher Δ was observed for lateral angle beams in most patients. This analysis could be used for select optimal beam angles for lung cancer patients treated with PBS protons.

2017 will be a challenging year for PSI, with the clinical commissioning of Gantry 3 and the planned shut-down of the ACCEL cyclotron. Stay tuned for some additional news in our next issue.

I take the opportunity to wish you a merry 'Xmas and a happy New Year to you and your families.

Yours sincerely,
Prof. Damien Charles Weber,
Chairman of CPT, Paul Scherrer Institute

General

20 years of high-precision combat against cancer

Gantry 1 with a patient on the couch fixed by a bite block

Developed at the Paul Scherrer Institute PSI, the spot-scanning technique for proton therapy celebrates its 20^{th} anniversary. This technique has been treating patients, gently and efficiently, since 1996. This development by the PSI researchers was a breakthrough at the time and quickly became a successful product: Today spot scanning is the standard method in proton therapy and is used worldwide in dozens of specialised centers. Already, more than 1200 cancer patients have been routinely treated with it at the Center for Proton Therapy of the PSI.

At the Paul Scherrer Institute 20 years ago, on 25.11.1996, the then brand new spot-scanning technique in proton therapy was applied for the first time worldwide to treat a patient. With wintry cold weather outside, a 62-year-old man from Canton Lucerne lay on the treatment table in the therapy station Gantry 1 and became the first person in the world to receive proton irradiation with the spot-scanning technique. His malignant skin cancer could not be treated and healed with the new method, but the metastases that had formed in his brain stopped growing. This afforded the patient several more years with a good quality of life.

In principle, proton therapy for treatment of cancer patients is much older than 20 years. Already in 1984, tumours in the eye were treated with protons at the PSI. With the development of the spot-scanning technique, it then became possible to treat tumours situated deep within the body more effectively. Since 1996, the number of treatment centers worldwide — ten at the time — has grown more than sixfold, with a continuing upward trend.

"When the first patient was treated with the spot-scanning technique at the PSI 20 years ago, it was a milestone in the history of radiation therapy," Damien Charles Weber, head and chairman of the Center for Proton Therapy CPT at the PSI, notes with pleasure on the occasion of the anniversary. "All the development work for the technology and the treatment facility, right through to the first practical application, took place here at the PSI. That was only possible thanks to the specialised expertise of our staff with respect to radiation physics, as well as with the infrastructure for proton beams at the PSI."

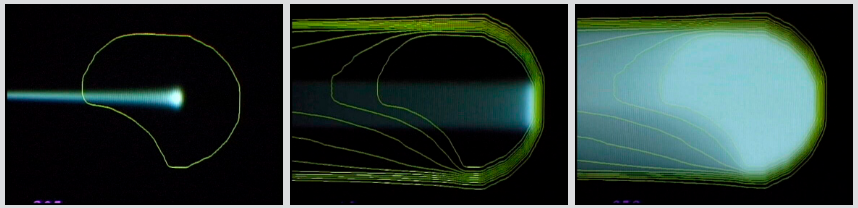
Gantry 1 is the first proton irradiation facility worldwide to function with the spot-scanning technique and is a home-grown development of the PSI. Its physical dimensions are impressive: It weighs 110 tons and has a radius of four metres. The final section of the beam path, which is carried by Gantry 1, is nine metres long. The gantry is so gigantic because 13 magnets are needed to steer the proton beam from all directions precisely to the patient's tumour.

Specifically for children, the spot-scanning technique has major advantages because it allows for especially precise treatment. In this method, the protons, in the form of a thin particle beam, are fired at the tumour layer by layer, whereby the proton beam scans the tumour from back to front, layer by layer and row by row. It is as if one wanted to fill in the three-dimensional form of the tumour with tiny points. The beam first reaches the deepest layer of the tumour; when this is filled in, the next higher layer has its turn, and so on. "It is almost like painting," Weber finds, "in which one first draws the background and then applies ever more layers over it." For that reason some specialists in this method also call it pencil-beam scanning. By the end of an irradiation treatment, the whole volume of the tumour from back to front has been hit by the beam.

Proton irradiation by means of spot scanning has proven its worth particularly for deep-seated, irregular types of cancers. Because this method allows the proton beam to be regulated with high precision, tumours that grow around the spinal cord, the optic nerve, or important organs can now, for the first time, be safely irradiated. Yet proton therapy is expensive and thus not the norm. Health insurance companies only cover the costs for a few types of cancer. Nevertheless, Weber believes in the great potential of the method. "We have shown that proton therapy with the spot-scanning technique is safe and effective for a variety of tumours," the doctor says. In current research projects, he and his team are working to refine the method still further.

Excerpt from a press release written by Sabine Goldhahn

The principle of the PSI-developed Spot-scanning technique:
Through the scanning and superposition of dose-spots of a proton pencil beam, the desired dose distribution can be built up, and the dose can be precisely tailored to the shape of the tumour in three-dimensions.



Physics News

Line scanning – a new irradiation technique

The Center for Proton Therapy at Paul Scherrer Institute looks back on 20 years of experience in cancer treatments using scanned proton beams. Gantry 1 was the first of its kind and developed for irradiations of localized, immobile tumor sites using the spot scanning technique. In 2013, our second generation gantry – Gantry 2 – went into clinical operation using an improved, state-of-the-art form of spot scanning. Besides, it features an additional, faster mode of operation called line scanning, which can be combined efficiently with common motion mitigation approaches (e.g. gating and/or rescanning). With the implementation of line scanning, we expect to expand the list of treatable indications from static to moderately moving targets.

Figure 1 illustrates the difference between irradiations in spot and line scanning mode. Instead of delivering dose to a fixed grid of discrete spot positions in the lateral plane (upper part), we steer the beam continuously along straight lines (lower part). Thus, we minimize the dead time (the time where the beam is turned off completely) to transitions from one line to another, rather than introducing dead time after every single spot. Both modes of operation benefit from fast energy changes (~ 100 ms between layers) when scanning through the tumor volume in depth.

In spot scanning mode, the delivered dose distribution can be modulated by assigning a different weight (or number of protons) to each spot position. Line scanning mode offers two degrees of freedom in dose modulation: (1) We primarily adjust the scan speed to control the dose deposition. Slow speeds yield high numbers of locally delivered protons and, thus, high doses, whereas fast scan speeds correspond to regions of low dose along the line. (2) If we scan at maximum speed already (2 cm/ms or 72 km/h) and wish to lower the delivered dose even further, we can additionally reduce the beam current extracted from the cyclotron within 0.1 ms. Gantry 2 is currently the only machine worldwide that can combine continuous speed and current regulation along single lines.

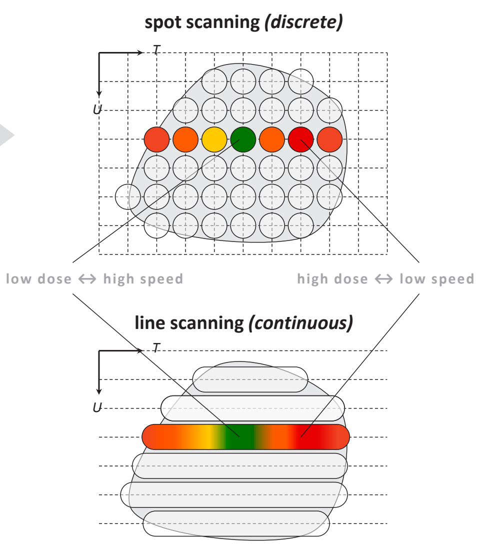
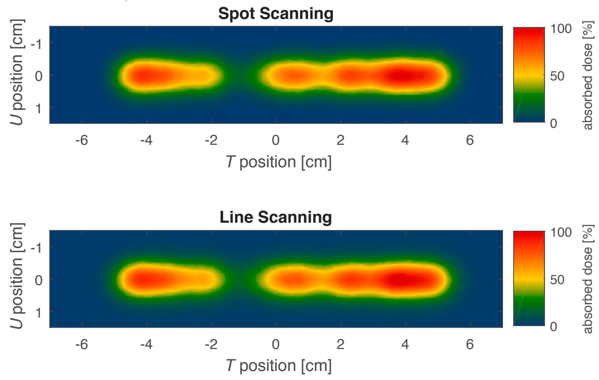


Figure 1: Schematic comparison of spot and line scanning. In the former delivery mode, protons are irradiated to positions on a discretized grid; in the latter mode, the proton beam is steered continuously along straight lines without being turned off in between.

Figure 2 displays measured dose distributions at iso-center delivered in spot and line scanning mode. For the former, weights between 10^6 and 10^7 protons were assigned to 26 individual spots (spaced 4 mm apart). The superposition of all spot doses yields a highly modulated distribution characteristic to intensity-modulated proton therapy plans. The total time of application amounts to 140 ms in this example. In line scanning mode, we are able to deliver the same dose distribution much faster. By assigning scan speeds between 0.1 to 1.0 cm/ms, we can irradiate the entire line in only 70 ms, which corresponds to a 50% reduction in delivery time. We see similar numbers when comparing delivery times of entire fields, e.g. liver tumor of 460 ccm planned target volume irradiated to 0.6 Gy. Irradiation in spot scanning took 51.5 seconds, whereas line scanning was completed after 26.7 seconds. The absolute differences increase even further when combining spot and line scanning with motion mitigation techniques such as gating and/or rescanning to suppress or wash out undesired interplay patterns.

Line scanning is currently at an experimental stage. Clinical integration requires smaller developments such as more precise regulation of the extracted beam current, dedicated treatment planning software as well as a dedicated monitoring system to ensure that irradiations in both modes satisfy equal safety standards. For the latter, we have already tested a prototype installation and completed part of the implementation on Gantry 2. The validation of the monitoring system is foreseen for 2017.

Figure 2: Delivery of a highly modulated dose distribution using both spot (top) and line scanning mode (bottom). Spot weights vary between 10^6 and 10^7; scan speeds span the range from 0.1 to 1.0 cm/ms. Line scanning is 50% faster in this example.



Line scanning is a fast and flexible beam delivery technique that offers the possibility to deliver highly modulated dose distributions through speed and current modulation. Thus, we consider it a well-suited technique to realize efficient and effective treatment of moving targets.

This work was presented at the International Conference on Translational Research in Radio-Oncology (ICTR) as well as at the 35th annual meeting of the European Society for Radiotherapy & Oncology (ESTRO) and won the ICTR poster award. We wish to thank the Giuliana and Giorgio Stefanini foundation for supporting this project.

For any further information, please refer to CPT:

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Medical-Physics News

Impact of beam angle choice on breath-hold pencil beam scanning proton therapy in lung cancer

Background

Pencil beam scanning (PBS) proton therapy has been suggested as a treatment modality for lung cancer patients, aiming to increase the overall survival by the possibility of decreased side effects or increased dose to the tumor. However, motion during PBS proton therapy may have a detrimental effect on the dose distribution. The breath-hold technique can be used to mitigate such effect, provided optimal reproducibility of the breath-holds. The aim of this study was to identify robust beam angles, to reduce the influence of the inter-fractional breath-hold variation.

Material and Methods

Based on the in-house treatment planning system at our institute, water-equivalent path lengths (WEPL) to the distal edge of the target were calculated. WEPL were evaluated for proton beam angles, sampled every five degrees, excluding beams entering through the contra-lateral lung. The differences of WEPL (ΔWEPL) were calculated based on two breath-hold CT scans per patient, acquired at the planning stage and at the end of the treatment, for 30 lung cancer patients.

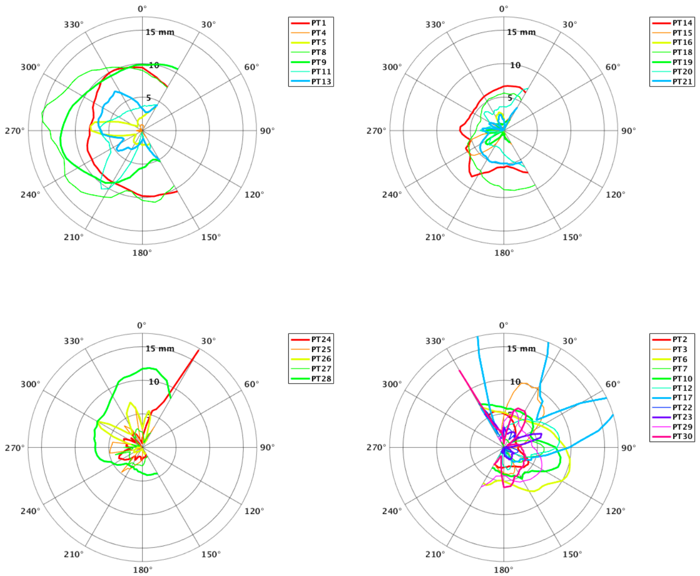

Figure 1: . ΔWEPL as a function of the beam angles in patient geometry for patients with right-sided (a-c) and left-sided tumors (d), respectively. The maximum ΔWEPL for patient 17 was 40 mm (outside the range).

Results

The ΔWEPL are shown in Figure 1 in the patient geometry for patients with right-sided (a-c) and left-sided tumors (d), respectively. Note the large variation between the patients and the slightly higher ΔWEPL around the lateral beam angles for most patients. In Figure 2, two examples of large and small ΔWEPL are shown (patient 1 and 16, respectively). The figure shows a good image registration for both patients, but patient 1's tumor is decreased in size, causing higher ΔWEPL. Clearly an adaptive therapy approach would be required in the latter case.

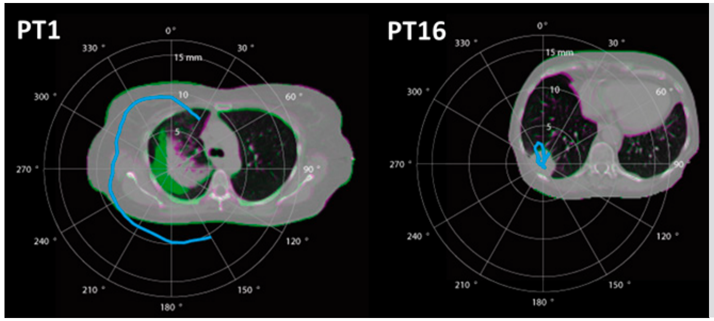

Figure 2: The ΔWEPL (blue line) for patient 1 and 16 as a polar plot overlaid on the image registration for the breath-hold CT scans. The green color represents the breath-hold CT at the planning stage, the magenta the breath-hold CT scan at the end of the treatment and the greyscale colors represents perfect match between the two breath-hold CT scans.

Conclusion

We demonstrated a method that could be used to select beam angles that could be performed in proton therapy planning based on WEPL differences using repeated breath-hold CT scans. The results show that the differences in WEPL with the BH technique are highly patient-specific, but lateral angles have a tendency of being less robust in a majority of patients.

This work was realized in a scientific collaboration with PSI, ETH Zürich, the University of Copenhagen and the department of oncology at the Rigshospitalet, Copenhagen.

The results were presented at the 4D workshop in Groningen, the Netherlands in early December 2016.

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