Protons have potential advantages over photons for delivering higher radiation doses to the tumor while sparing the surrounding healthy tissue. Though protons are inherently capable of higher dose conformity and lower integral dose to the body, the method of proton beam delivery is an important consideration as well.

**Beam delivery methods**

Two proton beam delivery methods are available today: passive spreading, which includes single and dual scattering, and active spreading, which is commonly known as scanning.

In passive spreading techniques, the proton beam is spread by placing scattering material in its path. A single scatterer broadens the beam sufficiently for the coverage of small fields. For larger fields, a second scatterer is needed to ensure a uniform dose profile. A combination of custom-made collimators and compensators conform the dose to the target volume. The spread out Bragg peak (SOBP) used for treatment is obtained by a set of range modulator wheels or ridge filters inside the gantry of the delivery system. (See Figure 1.)

In scanning beam techniques, magnets deflect and steer the proton beam. Under computer control, the beam “paints” the treatment volume, voxel by voxel, in successive layers. The depth of penetration of the Bragg peak is adjusted by varying the energy of the beam before it enters the gantry. (See Figure 2.)

(Top) Figure 1: Scattering diagram; (Bottom) Figure 2: Scanning diagram
How do these two delivery methods compare in a clinical setting? Are there differences in the conformity of the treatment, or the integral dose to patients? What should centers consider when choosing a proton therapy system? The following table addresses these questions through a side-by-side comparison of scattering versus scanning to help clinicians determine the most appropriate treatment method.

* Indicates advantage

<table>
<thead>
<tr>
<th>Scattering</th>
<th>Scanning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beam modifying devices</strong></td>
<td></td>
</tr>
<tr>
<td>Dual scattering uses patient-specific beam-modifying devices to conform the dose to the treatment volume. These devices must be manufactured in-house or outsourced, increasing the cost of treatment. Treatment cannot begin until the devices are ready. The devices, which become radioactive from contact with the proton beam, must be stored for months, necessitating a large dedicated storage area. This requirement increases facility costs without contributing to revenue.</td>
<td>In nearly all cases, scanning does not require any collimators, compensators, or other beam-modifying devices. A narrow mono-energetic beam paints the target volume in layers, steered by magnets. Varying the energy of the beam controls the depth of each layer. Typically with scanning, there are no modifying devices to custom-make or store after treatment, making scanning a greener treatment option.</td>
</tr>
<tr>
<td><strong>Secondary radiation</strong></td>
<td></td>
</tr>
<tr>
<td>Dual scattering generates neutrons when the beam hits the scattering material or the beam-modifying devices. This secondary radiation increases the integral radiation dose to the patient. Any radiation that does not directly contribute to destroying cancer cells is undesirable.</td>
<td>Without scattering material, scanning naturally produces fewer neutrons and reduces the integral dose to the patient. Limiting neutrons is especially important in the treatment of children, because they have an increased risk of developing neutron-induced secondary cancers later in life.</td>
</tr>
<tr>
<td><strong>Low integral dose</strong></td>
<td></td>
</tr>
<tr>
<td>Dual scattering deposits some unnecessary dose in tissues proximal to the treatment volume. This occurs because the spread of the Bragg peak is constant across the treated depth. As a result, some tumors close to sensitive critical structures may not be optimally treated with dual scattering. Using multiple fields is not an ideal solution in these cases; switching the complex set of compensators and apertures required increases the treatment time.</td>
<td>The smaller the treatment volume and the lower the integral dose, the better the patient is likely to tolerate treatment. Proton therapy delivers lower doses to healthy tissue than external beam therapy with X rays, and scanning delivers lower dose than other proton delivery methods. Figure 4 shows a scanning proton plan for the same treatment volume as shown in Figure 3, without the extraneous radiation of the dual-scattering plan.</td>
</tr>
</tbody>
</table>

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Figure 3: Dual-scattering proton plan

Figure 4: Scanning proton plan
Scattering

Studies indicate that intensity-modulated proton therapy (IMPT) results in lower integral dose than intensity-modulated radiation therapy (IMRT) with photons. Dual scattering cannot do true IMPT. The ability to vary the dose distribution throughout the treatment volume is limited with scattering. Multiple fields can deposit dose from different directions. However, multiple fields require a complex set of compensators and apertures, and switching them adds to the treatment time.

Scanning

Scanning makes IMPT possible. With scanning, dose distributions can be varied voxel by voxel. By varying the beam intensity or the speed of the scan, or both, dose is painted non-uniformly on a field-by-field basis to yield an overall uniform target dose. The scanning technique lets clinicians tailor treatments to improve dose conformity, reduce integral dose, or both.

### Sensitivity to organ motion

- Proton therapy poses the same challenges for accurate, repeatable patient positioning and setup as IMRT. In addition, bony structures moving in and out of the beam alter the range of the Bragg peak. The target volume and surrounding structures must be in their planned positions. This is true for all proton therapy techniques. However, scattering is more forgiving of tumor and organ motion because of the smearing effect of the broadened beam.

- Patient positioning and immobilization are important in all conformal radiation treatments. However, the enhanced ability with proton scanning to paint dose more conformally, voxel by voxel, increases the risk of target misses due to organ motion. This risk can be mitigated by image-guidance techniques. Multiple re-paintings can also compensate for organ motion by effectively smearing out the dose.

### Simplicity versus complexity

- Dual scattering is less complex than scanning. There are fewer variables to consider in planning. The beam is shaped to the target volume by using apertures and compensators (bolus).

- With scanning, clinicians have more flexibility to shape the beam. With this sophisticated capability comes increased complexity in planning, computation, and equipment.

### Depth of proton penetration

- When protons encounter scattering material and beam-modifying devices, they lose energy and, with it, penetrating power. For any given accelerator, scattering reduces the depth of the Bragg peak that can be obtained.

- With scanning, there are no scatterers or beam-modifying devices in the way to reduce the energy of the proton beam. For any given accelerator, scanning penetrates deeper than scattering. The result: scanning can treat deeper seated tumors.
Varian stakes its global reputation on giving patients and clinicians innovative treatment technology for fighting cancer.

Our mission is saving more lives, improving the quality of treatment, and providing solutions for treating the most challenging cancers. Proton therapy is one weapon in Varian’s advanced treatment arsenal, and we intend to drive its development forward as we have other modes of radiation treatment. Our pledge is this: when you want sophisticated, advanced treatments, you can turn to Varian.

References


