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Brief Communication

Proton Use in Radiotherapy: Superior Treatment or Flavour of the Month–An Overview

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Introduction

The use of charged particles as a treatment method was suggested by Robert R. Wilson in an article published in 1946 [1], after which the first treatments were given using particle accelerators at Berkeley Radiation Laboratory in 1954 [2]. Today, there are 18 centres in the United States (US), 13 in Japan, 7 in Germany, and a number of others scattered around the world [3]. Canada has one proton treatment facility situated at the University of British Columbia (Tri-University Meson Facility), which treats certain types of orbital tumours [4]. In Britain, three proton centres will be installed by 2017; this move came from public pressure resulting from a child being taken to Prague for proton treatment [5]. Although the number of treatment facilities is increasing primarily within US, this still is not a common form of treatment. This aim of this article was to provide an overview of how protons are created in a clinical setting, including a comparison of proton beams with other forms of radiation, the types of treatment machines available and, finally, a comparison of proton vs. photon treatment techniques using an example of orbit irradiation to illustrate the differences.

How Are Protons Created?

Protons are positively charged particles contained within the nucleus of an atom. They are commonly created by passing an electric arc through a narrow tube of hydrogen gas and pulled out through a narrow slit in the tube by an electric field. These ions are then fed into a particle accelerator such as a cyclotron or synchrotron.

Cyclotrons are made up of pairs of dipole magnets, which are parallel but slightly separated. Hydrogen ions are injected into the magnetic region in the centre of the magnets, causing the ions to move in a semicircular path until they reach the gap, where the protons are actually accelerated as they pass between the magnets. The direction of the magnetic field is reversed so the process happens again on the opposite side. In comparison, a synchrotron is a circular accelerator ring that uses electromagnetic resonant cavities around a ring, which then accelerates particles during each circulation. The advantage of a synchrotron is that it allows beam extraction for any energy, whereas the cyclotron is unable to change the energy of the extracted particle; the disadvantage is that they can be larger than a cyclotron [6].

A Comparison of Proton Beams with Other Radiation Beams

The proton is a heavy charged particle that loses speed and gives up energy as it interacts with tissue. Just before it stops, it gives up most of its energy at a specific depth. This is termed the Bragg Peak in an unmodulated beam [7,8]. It is this characteristic of depositing most of its energy at a precise depth that makes it different from both photon and electron radiation. The raw Bragg peak is often not wide enough to be useful for treatment purposes. Therefore, a spread-out Bragg peak (SOBP) is created by placing a beam modulator in its path, which creates many beams with different effective energies, thus allowing the beam used to cover larger tumour volumes. Figure 1 illustrates that the high-dose portion of the proton beam has been changed to a pristine Bragg peak to create the SOBP. In addition, Figure 1 compares the most commonly used radiation beams to the SOBP for a 200MeV proton beam. These beams deposit a peak dose after a short build-up region with the dose decreasing at greater depths of tissue forming the familiar percentage depth dose curve.

The main advantage of the proton beam is its depth dose distribution. The beam has a sharp fall off beyond its range, therefore no exit dose, thus allowing tissue to be spared beyond the lesion. Proton beams for therapeutic use range in energy from 70 to 250 MeV.

Biological Effectiveness

Protons are slightly more biologically effective than photons; therefore, a lower dose is required to cause the same

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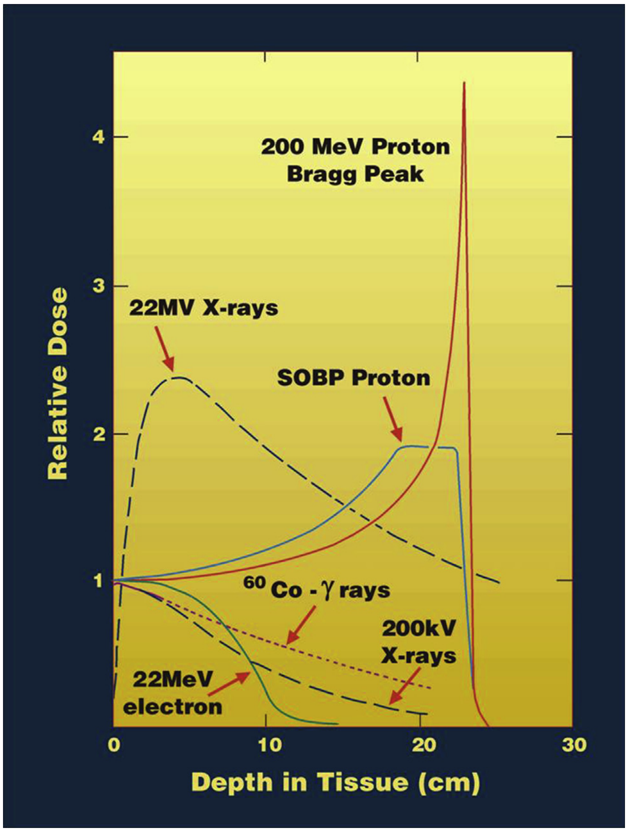

Figure 1. A comparison of depth-dose distributions for the most commonly used radiations with a 200 MeV proton Spread-Out Bragg Peak (SOBP) and Unmodulated or Pristine Bragg peak.

biological effect. This is well described by Paganetti and Bortfield in their review article "Proton Beam Therapy–State of the Art" [6]. The proton therapy dose is based on a single relative biological effectiveness value of 1.1 Gy in most institutions. This applies to the SOBP and is independent of dose and fractionation.

Dosimetry

There are data supporting equivalent cure using equivalent doses of proton vs. photons, with studies of proton and photon beam dosimetry demonstrating the superior tissue sparing and decreased integral dose with protons [9,10]. This reduction in integral dose also suggests a reduction in the expected incidence of radiation-induced secondary cancers [11]; in addition to this, there may be potential for reduction of late effects [12].

With the development of intensity-modulated radiation therapy and volumetric arc therapy or RapidArc® (Varian Medical Systems, Salt Lake City, UT), we now have the ability to dose escalate and sculpt isodose curves to follow contours of the tumour [13]. The use of these multiple beams or continuous arcs has also increased the volume of low-level integral dose to normal tissue within the path of the beam. Dose constraints can be placed on organs at risk to ensure the dose to those areas are kept within tissue tolerance; however, the doses outside this may be higher when compared with conventional therapy. Advancements in proton technology, including the development of a machine with a moving gantry, allow the creation of similar complex beam arrangements. Using this technology in conjunction with dose escalation and sculpting of idodose curves by means of the SOBP result in similar dose profiles when compared with photon treatment of the same site, while minimizing dose to the surrounding tissue. An example can be seen in Figure 2 [14] where the brain receives significantly more dose from the photon beam image A than the proton beam image B.

The risk of overdosing sensitive structures and geographical misses plays a bigger role. On-board imaging, now in common use on linear accelerators for intensity-modulated radiation therapy and volumetric arc therapy treatments, will play a similar role in development of more proton facilities throughout the world.

Treatment Machines

Proton treatment machines are becoming more common, with some facilities being purposely built for multiple proton

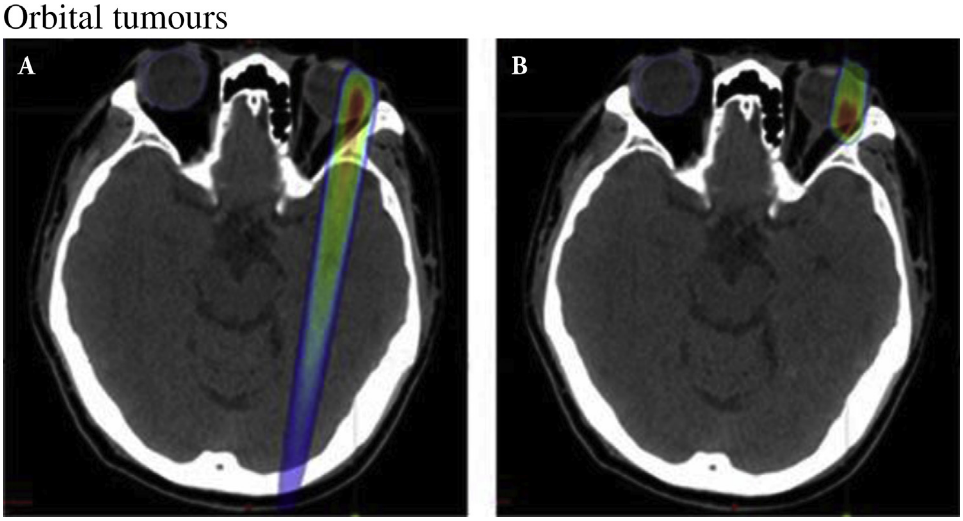

Figure 2. Treatment of an uveal melanoma (A) the treatment is planned with a photon beam and (B) with a proton beam. *Reprinted with permission from Proton Therapy Center, NCC, Korea* [14].