Chapter

Proton Therapy Center Layout and Interface

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Abstract

Due to space requirements and a substantial financial burden, the feasibility of health systems adopting proton therapy has been called into question. However, advances in facility design and treatment delivery have allowed institutions offering proton therapy to reduce footprint while incorporating technological improvements at reduced costs. As the number of centers and patients treated continue to increase, this chapter will review the layout and interface of proton therapy facilities providing a detailed overview of the design, costs and faculty and staff considerations.

Keywords: proton therapy, layout, footprint, radiotherapy

1. Introduction

The use of proton radiotherapy in oncology has gained renewed interest in recent years. The unique physical properties of protons and potential applications in radiation oncology were initially recognized by Robert Wilson in 1946 [1]. Soon after, the first patients were treated with proton therapy in the 1950's at the Lawrence Berkeley Laboratory [2]. Throughout the 1950's to 1970's, other institutions including the Harvard Cyclotron Laboratory, the Gustaf Werner Institute in Uppsala, Sweden and several facilities in Russia pioneered seminal studies that provided important insight demonstrating the advantages of proton therapy in the treatment of patients with cancers of the brain, eye, head and neck and skin [3–17]. This laid the groundwork for the transition of proton facilities from research institutes into hospital settings. Loma Linda University Medical Center was the first to accomplish this in the 1990's [18]. Since that time, the number of proton therapy centers and patients being treated worldwide has substantially increased [19].

As the demand for proton therapy has amplified, several vendors and facilities have attempted to address these needs through the development of new technology that reduces dose to surrounding structures. One such example is the advent of pencil-beam scanning that limits entry and exit dose to targets of large volume while achieving superior conformity when compared to photon therapy [20]. Although the use of proton therapy has increased with more centers being constructed in the United States and throughout the world, questions remain regarding core patient cohorts that will benefit from its use. Moreover, the clinical scenarios where the dose distribution advantages will provide better outcomes are still being elucidated [21]. This has led to hospital facilities questioning whether these potential benefits outweigh the financial and space requirements of a proton therapy center. Vendors have responded by supplying cutting-edge equipment, treatment planning systems, variations to existing proton beams and determining new ways to limit space. This has led to further innovations in proton therapy systems and a smoother integration with departments of radiation oncology and their existing photon system network.

In light of the continued evolution regarding footprint of proton therapy centers, this chapter will discuss facility design and equipment interface in order to provide an overview of the applicability of hospital-based proton systems.

2. Vendors

Mevion Medical Systems, IBA (Ion Beam Applications S.A.) Proton Therapy, Hitachi and Varian Medical Systems are the major proton therapy manufacturers throughout the world. Each vendor offers unique and advantageous proton therapy technology that allows health systems to construct a proton facility based on their specific requirements.

Mevion Medical Systems has developed many proton facilities throughout the United States with the most prominent located at the S. Lee Kling Proton Therapy Center at Siteman Cancer Center of Washington University School of Medicine and Barnes-Jewish Hospital [22]. Mevion developed the S250 proton accelerator system, which is a superconducting synchrocyclotron with a gantry-mounted proton source that rotates 190 degrees around the patient to facilitate optimal beam access. Specifically, the S250i series incorporates pencil-beam scanning for intensity modulated proton therapy by using a low-profile multi-leaf collimator system. For high volume proton centers, the S250MX system offers multiple room configurations and independent gantries.

IBA has established itself as an industry leader in proton therapy and has constructed numerous facilities throughout the world [23]. The Proteus system by IBA is also synchrocyclotron-based with the ability of pencil-beam scanning for intensity modulated proton therapy but incorporates a compact gantry that rotates 360 degrees around the patient. The general layout of a proteus-based treatment room consists of an open treatment enclosure, gantry rolling floor and in-room imaging control that, together, is about the size of two linear accelerator vaults. The reduced footprint and freedom in treatment plans are highly favorable characteristics for both hospital facilities and physicians.

Hitachi is also a leader in proton facility development as evidenced not only by the success of the University of Texas MD Anderson Cancer Center, but by several centers in Japan [24]. Hitachi offers a low footprint synchrotron with variations in gantries, which include full-sized 360-degree, compact 360-degree and 190-degree options. The type/s of gantry selected can be constructed into single room or multi-room designs to deliver intensity modulated proton therapy and real-time image gated proton therapy.

The development of the ProBeam 360 by Varian Medical Systems uses a superconducting cyclotron and 360-degree gantry to deliver intensity modulated proton therapy in single or multiple room configurations [25]. Each vendor offers effective technology that limits footprint, which leaves health systems options to determine number of treatment rooms, 360 vs. 190-degree gantry angle and if a synchrocyclotron, synchrotron or cyclotron is most appropriate for their needs.

3. Proton therapy center example-based layout

The design and layout of a proton therapy center is dependent on if it will be a part of a larger, hospital-based organization or a stand-alone facility. If a component of a radiation oncology department, then it will need to be determined if the proton therapy center will be located within the core department along with photon therapy equipment or at another location. Treatment rooms to be designed include the gantry, beam and control rooms as well as beam line and accelerator vault rooms, which include space for experimental setup and storage. As with any radiation oncology treatment facility, procedure rooms, examination rooms, reception area and administrative offices will need to be included in the overall layout.

The space requirements for a proton center are dependent on the number and size of treatment rooms as well as other medical and patient areas. The University of Texas MD Anderson Cancer Center proton facility was the first to be part of a National Cancer Institute (NCI)-designated comprehensive cancer center [26]. It is comprised of four rooms within a unit that is 96,000 total square feet. This includes a single beam room with two fixed horizontal lines, one for large volume targets and another for small volume targets (such as structures within the eye) while the other three rooms contain isocentric gantries. Proton therapy equipment at MD Anderson was acquired through Hitachi and treatment planning occurs through use of technology by Varian Medical Systems. Hitachi also developed the proton therapy center at St. Jude Children's Research Hospital, which consists of two rotating gantry rooms and one fixed horizontal beam room [27]. Proton therapy has demonstrated favorable results for several pediatric cancers [28], and this undertaking by St. Jude Children's Research Hospital further demonstrated the clinical importance of proton therapy for pediatric patients.

As mentioned above, IBA has constructed some of the largest proton centers in the country. The Roberts Proton Therapy Center at Penn Medicine is regarded as one of the world's largest centers, which offers both proton and photon therapy. It consists of four gantry rooms, a fixed beam room designated for treating conditions of the eye and a research room using the Proteus system by IBA [29] Similarly, the University of Florida Proton Therapy Institute is comprised of four gantry rooms and one fixed beam room, while the Francis H. Burr Proton Therapy Center at Massachusetts General Hospital has a fixed beam room for eye treatments and two gantry rooms [30]. Of note, the Francis H. Burr Proton Therapy at Massachusetts General Hospital initiated operations in 2002 after transfer from the Harvard Cyclotron Laboratory.

Another important example that highlights the versatility of proton facilities is the S. Lee Kling Proton Therapy Center at Siteman Cancer Center of Washington University School of Medicine and Barnes-Jewish Hospital, which was initiated in 2013 [31]. This system was the first gantry-mounted cyclotron and, accordingly, the first single-room proton center of its kind. The rotating gantry used by this system provides a platform for the beam to enter the treatment room from a 190 degree angle [31].

In 2020, the S. Lee Kling Proton Therapy Center expanded its operations through the addition of the Mevion S250i Proton Therapy System, which was installed directly next to the original system. This 1 + 1 expansion has substantial implications for limiting space requirements while increasing patient volume and delivering more efficient treatments, which incorporates Adaptive Aperture and Hyperscan technology. Of note, a collaboration between radiation oncologists at the S. Lee Kling Proton Therapy Center and Mevion Medical Systems have conducted research studying FLASH irradiation, which can deliver 200 Gy/s average dose rate at the Bragg peak and has potential in achieving higher tumor control rates than previously reported [32]. Collaborations between vendors and proton facilitates not only has potential for advances in research but facilitates the incorporation of clinical considerations into improvements in technology and treatment delivery.

4. Cost

In addition to space requirements, another major factor for health systems to consider in the implementation of a proton therapy center is the financial burden. The cost of the construction, equipment, technological considerations and staffing must all be taken into account. Although proton therapy has demonstrated more favorable dose distributions when compared to photon therapy [21], determining specific patients within a department of radiation oncology who are most likely to benefit may be a challenge. Moreover, it may also be helpful for health systems to consider the vicinity of other proton therapy centers and how this might affect their patient base.

Proton therapy centers have been reported to cost up to 235 million USD [33]. However, since vendors have developed technology that substantially reduces footprint, this has led to more feasible costs for health systems. Of course, this is dependent on the size of the facility, number of treatment rooms as well as if they are fixed-beam or gantry. In more recent years, proton therapy centers have been reported to cost closer to 25 million USD, which makes the cost/benefit analysis more reasonable for health systems. Perhaps not surprisingly, proton treatments have been reported to cost more than photon treatments [33], and this should also be considered when assessing facility returns and navigating the insurance process.

5. Faculty and staff considerations

Optimal efficiency of a proton therapy facility is dependent on an expert staff and smooth transition for patients during each aspect of their treatment (check-in, waiting area, consult rooms, on-treatment visit (OTV) rooms, simulation, mold preparation, and guidance to a treatment room being used for a patient's specific condition). Due to the generally large space of a proton center and the technical complexities it requires, having well-trained faculty and staff is imperative for execution of day-to-day operations. This includes physicians, physicists, dosimetrists, radiation therapists, radiation oncology nurses, machinists, operations engineers and administrative staff. The number of faculty and staff at a given time will depend on the size of the facility, number of patients being treated and quality assurance protocols for the specific equipment being used.

As photon therapy delivery requires specific training and experience, this is also the case with proton therapy. However, several potential challenges, which include the intricate details of proton therapy and lack of experience by faculty and staff predominately trained in photon techniques may result in a new proton center encountering delays and issues when it treats its initial set of patients. To minimize these potential issues, it may be helpful for radiation oncology departments who plan to construct a proton center to encourage faculty and staff to enroll in courses to familiarize themselves with the technical details and workflow. Organizations including the Particle Therapy Co-Operative Group and European Society for Radiotherapy and Oncology as well as institutions including the University of Pennsylvania, University of Texas MD Anderson Cancer Center and Mayo Clinic have offered courses, seminars and workshops to educate those who plan to or are currently involved in administering proton therapy.

6. Conclusion and future directions

As proton therapy evolves and become more prevalent, advances in facility design and treatment delivery are likely to continue that will make it more feasible for health systems to consider adopting. Vendors have responded by developing more affordable systems that reduce footprint while offering flexibility in number of fixed-beam or gantry treatment rooms. Pencil-beam scanning and variations in gantry angle are other advances that have shown considerable promise. Together, when also considering the favorable dose distributions of proton therapy, it is likely that the number of institutions offering proton therapy will continue to rise.

Going forward, it is critical that proton therapy facilities, vendors and physicists and engineers in both academia and the private sector continue to form collaborations that improve treatment delivery and imaging technology while reducing footprint. As proton therapy facilities gain more experience by treating larger numbers of patients, the knowledge they acquire should be relayed to vendors in order to improve patient care, develop more effective equipment and maintain a high-standard of quality assurance. Vendors should continue to have smooth processes that replace or upgrade outdated equipment. As always, questions and ideas should continue to be shared in society meetings, educational sessions and other forums.

Conflict of interest

The Authors declare no conflict of interest.

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