
Design for the Latest Technology in Cancer Treatment: A Carbon Therapy Center

Dyutima Jha, Assoc. AIA, EDAC, Healthcare Intern Architect and Medical Planner, Odell Associates Inc.

Abstract

Carbon therapy is the latest technology for cancer treatment; it is a form of radiation therapy not found in the present U.S. healthcare system but already being used in parts of Europe and Japan. The aim of this study was to understand the complex functioning of a carbon therapy center and derive design guidelines that determine the architectural response to it. The study was carried out by visiting prototype carbon therapy centers around the world and operational proton therapy centers in the United States. In addition, interviews with nuclear physicists, technicians, radiologists, and architects provided insights into the physics behind the technology, shortcomings of the prototypes, and the future of this modality of treatment. The study was focused on staff and patient needs, radiation shielding, wayfinding, stress reduction, and other physiological factors. Observations and comparisons were drawn to inform these selected parameters and reveal potential areas for new research.

The findings of the study were assimilated in a student project to design a carbon therapy center, sited at the University of Texas M D Anderson Cancer Center, illustrating the application of evidence-based principles to generate a design successfully integrating this novel technology while creating a humane environment for cancer patients.

Introduction

Cancer is one of the biggest healthcare crises in the world today. It is the cause of one out of every four deaths in the United States (Jemal and Siegel et al. 2008). Hence this disease requires the utmost attention, and it is extremely vital that we be better prepared to fight it. Some of the common forms of cancer treatment currently being used are chemotherapy, surgery, targeted therapy, immunotherapy, photodynamic therapy, antiangiogenesis therapy, hyperthermia, and

radiation therapy. Over the years, new methods of treating cancer have revolutionized the world of healthcare and in turn influenced the architectural response to it. Gamma rays replaced by x-rays, and then radiation therapy became the most widely used form of cancer treatment, with two out of every three patients being treated with it (Mandrillon 1993).

Research with proton and ion beams has been conducted for almost 50 years, and thousands of patients have been treated with proton therapy. It is considered one of the biggest advancements in the history of cancer treatment. Its efficiency and effectiveness have made it a popular method of treatment. The number of proton therapy centers in the United States has grown from two to ten in the last decade, with a large number of proposals for future centers.

What Is Carbon Therapy?

Although proton therapy has taken the lead today, there is another variation of radiation therapy making its way into the world of cancer treatment: carbon therapy (Mandrillon 1993). Currently being used mainly in parts of Europe and Japan, this therapy is on the verge of revolutionizing cancer treatment.

As the name suggests, carbon therapy is a technology in which heavy ions of carbon are accelerated with calculated velocity to target deep-seated tumors. It is usually used to treat tumors in the lungs, cervix, head, neck, liver, prostate, or soft tissues, all of which are difficult to operate on and cannot be eradicated effectively by conventional treatments. Inoperable tumors for which no other treatment is available or tumors located close to sensitive organs, such as the spinal cord or optic nerve, can be treated effectively with carbon therapy because of the dosage distribution and depth of penetration possible (Brower 2009). The use of carbon ions in radiotherapy came into practice in 1994 in Japan. Since then, each step forward

Over the years,
new methods of
treating cancer have
revolutionized the
world of healthcare
and in turn influenced
the architectural
response to it.

The walls of the treatment room are generally made of concrete or a combination of steel plates and concrete, since these materials have the maximum capacity to absorb and prevent leakage of radiation.

has worked to maximize the capability of these ions to cure without harming healthy tissues in the body.

Treatments like standard chemotherapy do not differentiate between cancer cells and normal cells, and hence destroy both equally, a major reason why chemotherapy has such adverse side effects (retrieved from <http://news.bbc.co.uk/2/hi/health/4734507.stm>). Proton ions offer some respite in preventing excessive damage to healthy tissues, but carbon ions have an even greater advantage in this regard (Miyamoto et al. 2003). They offer the benefit of using higher dosages of radiation while considerably reducing the harmful effect on healthy tissues (Schulz-Ertner and Tsujii 2007; Mizoe, Tsujii et al. 2004). The peak at which ions possess maximum energy right before coming to rest is called Bragg peak. Being larger in size, carbon ions achieve a sharper Bragg peak and destroy tumors more efficiently compared to protons (retrieved from <http://www.gsi.de>; Schulz-Ertner, Nikoghosyan et al. 2004). This property also makes them a useful supplement to surgery. Exposure to carbon ions before or after surgery does not harm healthy tissues and can help reduce the size of the tumor. Carbon therapy is also used in addition to proton therapy and x-rays (Brower 2009).

The Process

Once approved for carbon therapy, patients undergo a simulation process. A customized immobilization mold is created for every patient. The mold helps to obtain accurate x-ray images showing the exact position and size of the tumor. Imaging allows the tumor to be detected and analyzed.



Figure 1: Siemens design of the patient table with the robotic arm for accurate positioning before treatment (retrieved from <http://www.siemens.com> on May 22, 2011)

Based on the results, physicists plan the course and duration of the treatment. When the patient returns for carbon-ion therapy, images are taken using x-ray or ultrasound technologies, which are compared to the pretreatment images to ensure precise alignment of the patient with respect to the beam. The treatment begins only after accurate positioning of the patient is complete.

Main Components of a Carbon Therapy Center

Waiting area

Given the treatment and course of the disease, cancer patients experience high levels of stress. The novelty of the treatment and its high cost can be intimidating factors as well. The main waiting area is the first point of contact for patients. Hence, it is essential to determine design interventions that create a calm and relaxing environment, thereby enhancing the overall patient experience.

Changing area

Based on existing carbon therapy centers there are two different approaches to designing changing areas. Both have varying impacts on the circulation pattern and patient experience.

In the first approach, patients are directed into changing rooms from the main waiting area. After changing, they proceed to a common waiting room before immobilization. The second approach is to provide individual changing areas outside each treatment room. Patients wait in their respective changing rooms until directed to proceed for immobilization. In this case proximity to the control area raises issues of HIPAA violation and lack of patient privacy. Though this design is more convenient in terms of space planning, it has been observed that patients feel more relaxed in the company of other fellow patients, although this observation has yet to be validated.

Immobilization room

Positioning of the patient is an important determinant of the workflow. There are primarily two locations in which immobilization can be carried out: inside the treatment area or in an immobilization room outside of the treatment area.

- Inside the treatment room: Patients place themselves on the table when they are brought into the treatment room. The therapy is carried out on a patient table similar to a tabletop. This table is connected to a robotic arm that helps adjust the patient's position (figure 1).
- Outside the treatment room: The provision of an immobilization room outside the treatment area facilitates the positioning of the patient before treatment begins. This room is equipped with a tabletop connected to a shuttle, which helps align and transport patients for treatment or imaging. The therapy area includes a robotic table base that docks to this tabletop and makes positioning accurate yet comfortable for the patient. The general time frame for patient positioning is around 30 minutes. When performed outside, the use of treatment areas is maximized. Patient scheduling can be optimized by reducing the immobilization time

for each patient and allowing greater usage of the therapy rooms.

In both cases, technicians verify the position via robotic x-ray imaging or cone beam computed tomography. Verified data is transferred to the control area located close to the treatment room or right outside it.

Treatment room

During the treatment process, neutron particles are generated in parallel with the carbon ions. Thus, radiation shielding is a major issue in these areas. To ensure that these particles are guarded within the confines of the treatment area, the entrance to the room is designed as a maze so that the neutron particles are unable to travel long distances. They collide with the walls of the maze and are unable to reach outside the room. The walls of the treatment room are generally made of concrete or a combination of steel plates and concrete, since these materials have the maximum capacity to absorb and prevent leakage of radiation. The walls, ceiling, and floor generally have a minimum thickness of approximately 3 ft. The exact thickness is calculated by physicists and depends on a number of factors. The typical size of a treatment room is about 40 ft x 60 ft but can vary depending on the type of beam being used for treatment. Beams can be vertical, horizontal, or angular. A combination of vertical and horizontal beams can also be used for more precise treatment. Vertical beams require treatment rooms with additional height in order to accommodate the beam coming from the upward direction. Treatment rooms with angular beams can either have a fixed angle (30 or 45 degree) or a gantry (360 degrees) to generate the accurate angle, depending on the location of the tumor.

Gantry room

The gantry occupies the maximum volume of space. A typical gantry used for bending carbon ions is about 13 m in diameter, 25 m in length, and over 20 m in height; it requires an area of approximately 340 sq m. The design of this space is extremely complicated because a gantry is usually housed in a room rising up to three levels. The lowest level is

The waiting areas on both levels were designed to relieve the extreme stress that patients undergoing this therapy may experience.

The equipment area in a carbon therapy center is divided into three components: ion source, injector (linear accelerator), and synchrotron/cyclotron room (figure 2).

usually an accessible space for inspecting the equipment. The middle level is the treatment area, and the top level is a balcony for viewing the equipment. These levels are connected internally through a means of vertical circulation and feature an entrance from each level.

Control room

There are three levels of control in a carbon therapy center. They each function in collaboration to ensure safe, efficient treatment.

1. Inside/immediately outside the treatment room: A small control area is provided inside the treatment room or immediately outside it with work space for one or two technicians. The main function of this room is to verify the position of the patient. Each treatment room has its own control area.
2. Common control area: A larger common control area, typically across the treatment rooms, monitors the activity taking place during beam emission. It is

usually not an enclosed room in order to enable free flow of information and easy access to treatment rooms.

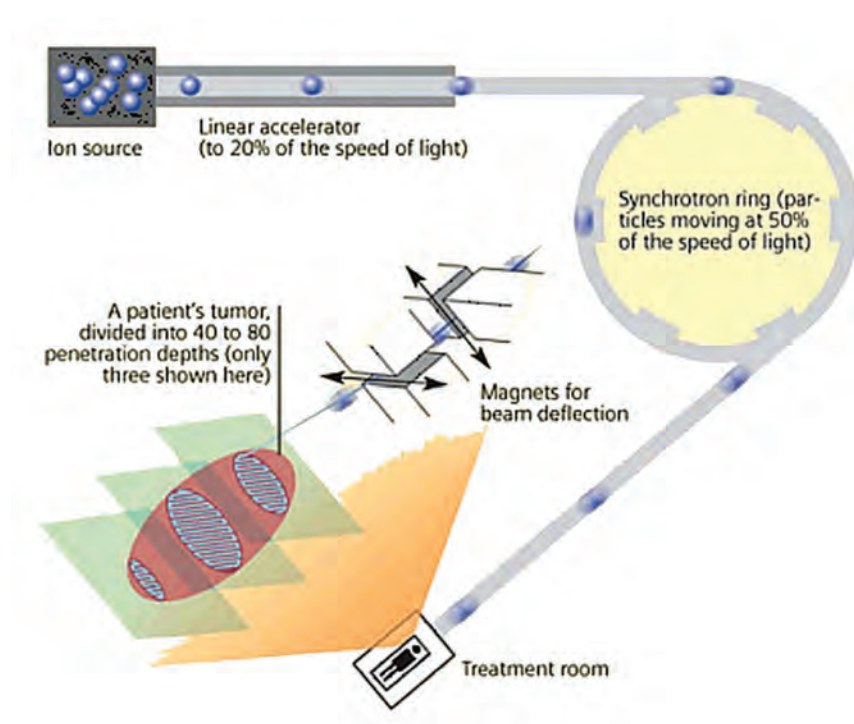
3. Dosimetry control room: This is the main control area, which monitors the entire process beginning with the production of ions from the source, the process of acceleration in the injector and synchrotron, and the delivery of the beam into the treatment room. This room is the largest in area as compared to the other control rooms. The preferred location of this room is close to the common control area; it is not located near public or patient accessible spaces.

Equipment room

The equipment area in a carbon therapy center is divided into three components: ion source, injector (linear accelerator), and synchrotron/cyclotron room (figure 2).

The linear accelerator is located between the ion source and the synchrotron. Its function is to provide the initial acceleration to the particles before reaching the synchrotron. The length of the linear accelerator room is typically between 5 m and 10 m. Even though linacs would be more cost-effective since they do not use bending magnets, radiation therapy with protons and carbon ions requires high power linacs that have to be extremely long to be able to provide the required velocity to particles. Hence, circular accelerators such as synchrotrons or cyclotrons prove to be more beneficial. Initially the synchrotrons used to accelerate carbon ions were 20–30 m in diameter and about 65 m in circumference. Advanced experimentation has led to a new design solution enabling the ion source and the injector to be included within the circumference of the synchrotron ring. This largely decreases the overall length and size of the equipment area, which is a huge concern in such centers. The diameter of the synchrotron in the new compact design is about 10 m. The specification of material and wall thickness is the same as the other shielded areas.

Figure 2: The complete sequence of production of carbon ions to utilization for treatment (retrieved from <http://www.siemens.com>, October 30, 2010)



The Design: An Evidence-Based Approach

The observations and conclusions drawn through this study were summarized in the design of a carbon therapy center sited on the campus of the MD Anderson Cancer Center in Houston (figure 3). The main idea was to use evidence-based principles and best practices to generate an architectural solution for this technology, also aimed at reducing patient and staff stress and facilitating wayfinding.

The carbon therapy center was designed on three levels. The carbon ion treatment area was placed on the first floor, below grade, in order to use the earth around it as a natural shield for radiation (figure 4). Thick concrete walls and huge equipment spaces can prove to be detrimental to easy wayfinding. As a response, transparent and linear circulation routes were created to help patients orient themselves at any given location within the facility (figure 5).

Imaging, examination, and other support areas were located on the second floor, which was also the entry level (figure 6). Since these areas needed to be adequately shielded, they were located toward the center of the building, making it possible to provide windows on the periphery and bring natural light into the facility. The waiting areas on both levels were designed to relieve the extreme stress that patients undergoing this therapy may experience. Courtyards on both sides of the corridors leading to the procedure areas provide a positive distraction for patients, and a series of green areas throughout the building continues the patient experience from beginning to end (figure 7).

The third floor occupied a smaller footprint and housed administrative and office areas (figure 8). The idea was to use the therapeutic effects of nature not only for patients but also for staff (Hartig and Marcus 2006). For the same reason, this floor was designed with a balcony overlooking a green roof. Most of the staff work and respite areas were provided with window views and access to natural light. The privacy of the users was maintained

Figure 3: Perspective views



Figure 4: First-floor plan: Procedure and equipment areas were designed below ground level to use the earth around the building as a natural shield for radiation. The layout of the equipment room was based on the latest concept of locating the ion source and the linear accelerator within the circumference of the synchrotron ring, thereby decreasing the amount of space required. A horizontal beam treatment room, an angular room, and one with a gantry were designed to illustrate different room types.

Using evidence-based design to determine architectural solutions for this facility type could be a real breakthrough.

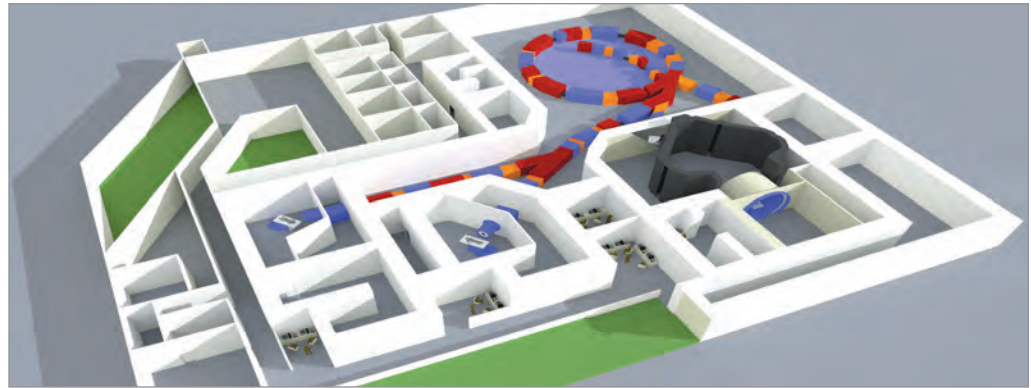


Figure 5: Layout of the carbon therapy procedure area

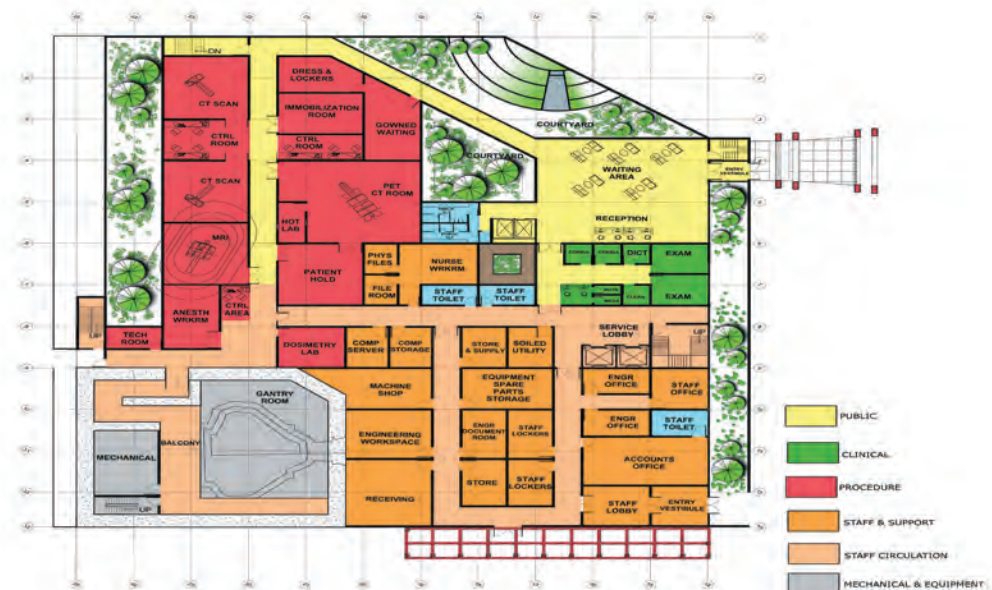


Figure 6: Second-floor plan: The entrance was designed at the same level as the imaging and support areas. A series of courtyards throughout the building balances the intimidating and sterile components with soft, sensitive elements. Evidence-based principles were adopted to create a design that reduces patient and staff stress and facilitates wayfinding.



Figure 7: View of the courtyards from the waiting area

by a peripheral wall running along the entire circumference of the building, also lending an aesthetic character to it.

The biggest challenge of this project was balancing the sterile and intimidating aspects of the building with soft, sensitive elements (figure 9). The effort was to develop an understanding for the technology and translate it into architecture that responds positively to its users.

Challenges of Carbon Ion Therapy

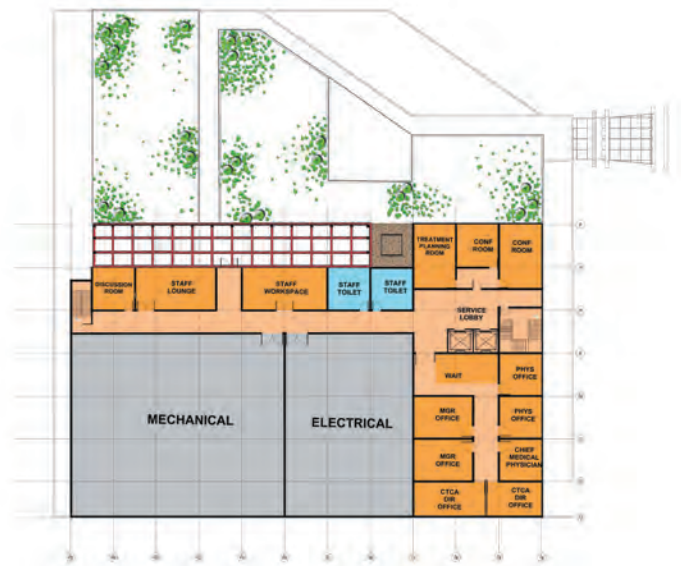
High cost and lack of sufficient research are the probable reasons for the absence of carbon therapy from the American healthcare system. Although U.S. researchers are interested in the technology and treatment, several of them feel that scarcity of data and clinical trials obscure the prediction of the effect of this technology in the long run. Another major issue is the expensive and difficult expansion/conversion of a proton into a carbon facility.

Increase return on investment of carbon therapy facilities

Because this technology is relatively new and unexplored, it is extremely expensive, and the construction cost of such facilities is high. There is a need to find innovative ways to balance the initial investment with the ongoing operational costs. Using evidence-based design to determine architectural solutions for this facility type could be a real breakthrough. Increasing the number of facilities could also help reduce the capital investment by providing competition in the market.

Size of the equipment

Downsizing the facility to reduce costs is essential. With nano-technology being the order of the day, the size of the equipment needs to be reduced. Smaller equipment will enable hospitals and other existing facilities to include this treatment in their facilities, thereby generating higher revenues.



To evaluate the effectiveness of the technology in comparison to proton therapy

It is critical to conduct more research and clinical trials in order to determine the effectiveness of carbon therapy compared to proton therapy and other forms of cancer treatment. Tumors are often treated first with protons and then followed up with carbon ions to increase the chances of successful eradication of the tumor. Hence, it is important to find out which diseases and cancer types respond to carbon therapy. Such data will help the technology be accepted worldwide and encourage further research in this field.

In spite of the present reticence, many believe that the increase in the number of carbon therapy centers in Europe and Japan will produce sufficient evidence to prove the validity of this technology to the rest of the world including the United States (Brower 2009).

Figure 8: Third-floor plan:

Administrative areas were designed with access to natural light and views of nature. An outdoor terrace overlooking the green roof was created near the staff lounge to provide respite in a stress-reducing environment. The mechanical and equipment areas were located in the southwest part of the building as a response to the local climate.



Figure 9: Sections illustrating the relationship between hard and soft elements

Acknowledgments

The author would like to acknowledge Prof. Kirk Hamilton, Dr. Susan Rodiek, Dr. Mardelle Shepley, Prof. George Mann, and Dr. Stephen Guetersloh from the department of architecture, and architects Rick Kobus, Erik Mollo-Christensen, and Johathan Cohen from Tsoi/Kobus & Assoc. for their unremitting support and guidance.

Note

This study was funded by the AIA AAH Arthur Tuttle Fellowship in Health Facility Planning and Design and the David Puckett Healthcare Architecture Prize, Architecture Center Houston Foundation. Site visits to carbon therapy centers in Heidelberg and Darmstadt, Germany, and Chiba and Gunma, Japan, were conducted, in addition to proton therapy centers in Texas and Massachusetts. The design portion of the research was also submitted as part of a "final study" to the department of architecture at Texas A&M University toward partial fulfillment for the Master of Architecture degree. The study was presented at the 2010 Healthcare Design Conference in Las Vegas.

References

- Brower, V. 2009. Carbon ion therapy to debut in Europe. *Journal of the National Cancer Institute Advance Access* 10 (2).
- Hartig, T., and Marcus, C. C. 2006. Healing gardens—places for nature in health care. *Lancet* Dec 2006 supplement, vol. 368: 36–37.
- Ion-beam radiotherapy in the fight against cancer. 2006. Retrieved February 20, 2009, www.gsi.de/documents/DOC-2006-Aug-25-1.pdf.
- Jemal, A., Siegel, R., et al. 2008. Cancer Statistics. *CA Cancer J Clinic*, 58, 71–96.doi: 10.3322/CA 2007.0010.
- Mandrillon, P. 1993. Cancer therapy with ions. In Elsevier science publishers B.V (ed.), *Nuclear physics*, 349–360.
- Miyamoto, T., Yamamoto, N., et al. 2003. Carbon ion radiotherapy for stage I non-small cell lung cancer. *Radiotherapy and Oncology* 66: 127–140.
- Mizoe, J. E., Tsujii, H., et al. 2004. Dose escalation study of carbon ion radiotherapy for locally advanced head-and-neck cancer. *International Journal of Radiation Oncology Biology Physics* 60 (2): 358–364.
- Nanotechnology kills cancer cells. 2005. Retrieved February 15, 2009, <http://news.bbc.co.uk/2/hi/health/4734507.stm>.
- Schulz-Ertner, D., Nikoghosyan, A., et al. 2004. Results of carbon ion radiotherapy in 152 patients. *International Journal of Radiation Oncology Biology Physics* 58 (2): 631–640.
- Schulz-Ertner, D., and Tsujii, H. 2007. Particle radiation therapy using proton and heavier ion beams. *Journal of Clinical Oncology* 25 (8): 953–964.