Investigation of Hadron Therapy Using Laser Accelerator Compared with Cyclotron Accelerator

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***Abstract*— Today Hadron therapy account for as a new approach in radiation therapy. Since compared to photon therapy can protected more healthy tissues from unwanted damage. And in addition, in terms of their outstanding radiobiological properties, has improved the efficiency of cancer treatment with increased the risk of tumor growth control. During the years that have passed since the invention of hadron therapy treatment systems upgraded for even better treatment and there has been considerable progress. Among these choosing the type of accelerator always been a key and challenging issue and in the following way. The most important characteristics of laser accelerator, having low weight and afew dimensions due to the compact components, short-guards against the rays, and be small and afew number of magnets conductivity and transfer the beams and in addition to being equipped with compactness gantry, these advantages for medical radiation oncologists provides therapeutic appropriate action. Meanwhile impossible treatment of some tumors with conventional methods and conventional accelerator, according to the features of a charged particle beam, ease of changing the intensity of the pulse, being spot beam, and capabilities expanding of the range of beam and doses distribution, with these system is possible. These technology is particularly important in promoting the new method of biological adaptive of radiation therapy. In this paper has been studied the application of high-energy accelerators, such as a cyclotron, and also parameters of selection an accelerator according to the needs and requirements be analyzed and investigated.**

***Keywords*— hadron therapy, Laser accelerator, Cyclotron accelerator, Tumor, Transfer of Beam, Energy and dose distribution.**

I. Introduction

Hadron is a term used for the introduction of subatomic particles that are made of quarks. As well it refers to particles such as proton, carbon, neutron and pion, hadrons in this article due to the high clinical application of proton and carbon it refers to these two particles and called hadrons. [1,2]

Hadron therapy is one of the radiation treatments with heavy charged particles has emerged a modern technique in the treatment of cancer. Despite the great progress so far has been made in radiotherapy in this way, but exponential drop of primary photon due to the nature of the interaction of photons with material remains as a main challenge. [3] Since the photon dose decreases exponentially and on the other hand they would travel long distances in tissues and their surroundings before these particles stop, therefore organs before and after the tumor tissue, receive significant dose so unwanted side effects after radiation therapy with an increased risk of second cancers due to unwanted radiation to non-target tissues is still the main concern of this therapy. [4,5]. In contrast, particles such as protons and carbon due to its unique physical dose distribution can penetrate deeper tissues and suddenly deliver most of their energy at the end of the path to the target point and immediately stop that is known maximum dose of the Bragg peak (see Figure 1) [6]. From the other attractive physical properties of heavy charged particles mentioned the ability of Spread Out Bragg Peak (SOBP) in the volume target using modulated multiple Bragg peaks with different energy levels, with these unique characteristics of the dose distribution can protected healthy tissues from higher levels of unwanted damages and thus reduce side effects associated with them such as secondary cancers [7-9].

In addition, higher linear energy transfer (LET) of hadrons than electrons and photons leads to more relative impact of radiobiology (RBE). Hadrons thus raising the likelihood of a double failure (DBS) through direct interaction with DNA molecules in the nucleus of cells, the efficiency of treatment response cancer cells increase [10-11]. And thus, the chance of treatment tumors resistant against X-rays and gamma increase [12].

Another important point in the application of hadrons can mentioned their ability to bend the path electromagnetic fields this important property lead to design high-precision dose delivery systems and also provided possibility of designing of high-energy accelerators [8.13] which are described in more detail in the following sections. A look at the features and benefits of the mentioned advantage show that between 1960-80 AD years have been made meaningful efforts to develop proton therapy centers, although before the Loma Linda University Medical Center has already established in Southern California (1990), all these centers were located in physics laboratories and this event was the beginning of transmitting the centers of physics laboratories to hospitals [14-15] followed by this, world have witnessed the development of such centers, especially in the United States and Europe and few Asian countries. The exact statistics of active centers are launching and the number of patients who have been treated, is published each year by PTCOG (Particle Therapy Cooperative Group). According to the latest statistics published in 2015, has nearly 53 Hadron therapy centers around the world in clinical practice are working and in mentioned centers, more than 123,000 patients have been

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treated with proton and carbon that proton's share was close to 108,000. In addition, statistics show that the number of centers is growing at the design stage and the Commission [16].

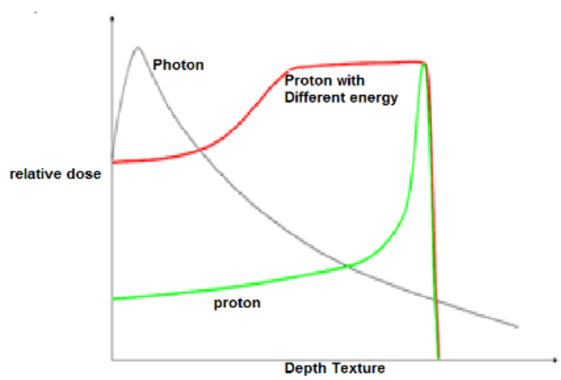

Fig. 1. Comparison of depth dose profiles photon and proton in terms of depth in body tissues. While photons deliver much of the dose to initial deep-tissue, proton has capability to deliver dose in deeper layers. A SOBP curve drawn by using protons with different

II. Features of Hadron therapy laser accelerator

Some of the most important technical characteristics of laser accelerators in radiation therapy with the help of particle include:

A. Be small

The laser accelerator must be compact enough because according to the existing facilities and infrastructure available in each hospital can be assigned to the appropriate space. Gantry is naturally small because it not requires large magnets in conventional accelerators for transferring the laser photons. Shielding for conventional accelerator is complete and comprehensive but brief and regional for laser accelerator.

Laser acceleration compared with other accelerators is very concise and simple because the most expensive and most complex element of it is laser and since lasers are rapidly becoming cheaper and more powerful it has important contributions to the development accelerator in radiation therapy [17].

A system of radiation therapy equipped with lasers accelerator, usually include a laser system with multi-terawatt power, a chamber producing beam a magnetic separator system and a system for patient settlement. This feature is very noticeable compared with a cyclotron. [18].

B. Beam transfer

In general, laser accelerators easily placed within the beam transmission system, because laser light guided and orientated by the mirrors and by the last mirror is concentrated on the purpose for which it acts as an accelerator. Another point is that the laser accelerator there is no need to use ion injection. (Figure 1).

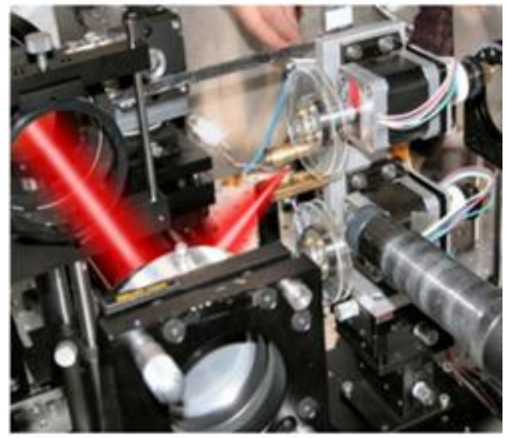

Fig. 1 -Laser alignment tool accelerator

C. removing small tumors:

Because the extent of working this type of accelerator is in the range of a few centimeters, it can be used in removing small excrescence.

3. cyclotron

Cyclotron is a accelerator ring shape for charged particles and x-rays produced for various tests generated.

The process of acceleration of particles in a cyclotron:

Generally, in the process of acceleration of charged particles and radiation transmission systems Lorentz equation can be considered as follows:

$F=q(E+V\times B)$

In this equation F vector is force on a charged particle with charge q with velocity v, in the presence of an electric field E and magnetic field B is determined in mere presence of an electric field particles accelerates in a linear path, however, if a magnetic field is applied perpendicular to the direction of motion of the particle, in this mode path of the particle movement without changing in the energy acquisition in the electric field converted to curved path. The radius of curvature can be calculated by the following equation:

$B(kG)\rho(m)=33.35\ p(GeV/c)$

So that a single particle with momentum p (in GeV / c) in a magnetic field B (in kilogauss) in a radius ρ (meter) be curvature [19].

Cyclotron is a compactness accelerator with several main components (see figure 2) and the injection to extract process protons in a cyclotron can be summarized as follows: (A) cyclotron is a source of low-energy protons which are usually located in the center of cyclotron that ionization stage of hydrogen gas to injection in machining center perform in it. (B) Radio frequency (RF) systems which supplies electrical field to accelerate protons between D-shaped plates (Dees). (C) - A strong magnetic field that changes path of movement of acceleration protons in a spiral path. (D) An extraction system that lead maximum energy particles that have been accelerated after the process of turning [20]. For more information see references [19-20].

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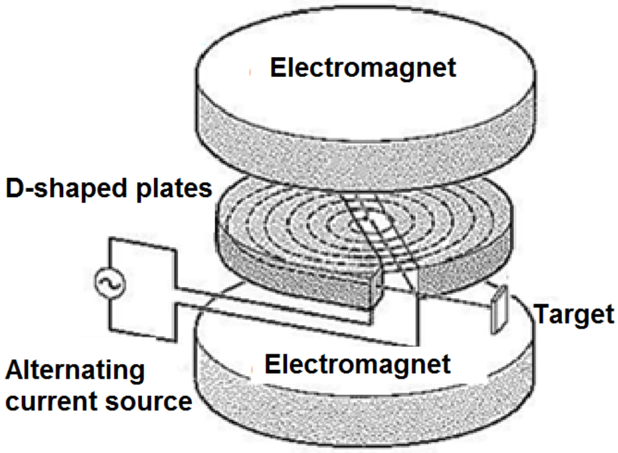

Fig. 2. The path of particles in a cyclotron that are accelerated in an electric field and magnetic field simultaneously

III. Properties of Output Beam of Cyclotron:

As explained in section 3-1, as soon as the accelerated protons reach to the maximum energy, extraction process from accelerator is done. From important advantages of output beam in cyclotrons can be named the continuity of output beam and the ability to control the intensity of the beam in desired speed range [20]. In addition, one of its advantages is the simplicity of design principles.

However, since the particles in cyclotrons accelerated at a fixed frequency and in the presence of electric and magnetic fields, energy of output beam almost is single energy (250 -230 MeV). So in order to establish a SOBP appropriate to output beam lead to energy selection system (ESS) and by the energy reduction or in other words board displacer, Bragg peak at depth displaced to superposition of Bragg peaks with different depths of penetration resulted in an area of smooth dose. This cause to produce pollution due to the interaction of beam with physical components in the beam path in the system and consequently the beam intensity for high-energy protons with low energies than high energies have tangible reduction [19].

Another major limitation in the design of cyclotron for accelerating particles in the range of mentioned energies, its weight and diameter has been due to the use of copper in the manufacture of coils to generate strong magnetic fields but today, with the use of superconducting materials in the construction of the cyclotron magnet the problem to a large extent has been solved [19].

A. Characteristics of beam distribution with the laser and cyclotron conductance:

Laser distributor of energy to treat small tumors distribute an average of 1010 particles per pulse. Many of performance tests shows about 109 particles per pulse. Hence, the energy of laser accelerator to reach the desired proton flux there is still a large gap, but compared with beam distribution system with cyclotron help, has a much higher efficiency [21].

B. Limitations contained in laser and cyclotron accelerator:

To date, the maximum of beam energy of produced proton without laser accelerator that has been measured experimentally, has been limited to a few 10 MeV.

IV. Characteristics of Cyclotron Accelerator System Compared with a Laser Accelerator:

Important and discussable parameters in this comparison included beam transfer, accelerator, technical characteristics and clinical features (such as device size and importance of occupying space in a health center).

Characteristics	cyclotron accelerator	Laser accelerator
Beam transfer	Relatively larger magnets for leading charged particles and protection against beam around the beam transmission line	Bending and transferring of beam with mirror and do not need for protection against beam around the beam transmission line
Accelerator	Dual acceleration particles: optional acceleration deuterons between 15 and 19 MeV O.F allows the production of compounds This system is also useful for research applications .	radiation Only to the target part and thus the possibility to brief the system
Energy	around 30MeV	A few 10 MeV
Cost	Relatively cheap	cheap
Dimensions	relatively large	small (can be installed on a desk)
Clinical applications	Solid tumors inside the body	Small tumors and in low depth

V. Precursor Challenges in Accelerators of Hadron Therapy

Existing evidence shows that many therapies have been conducted in centers with a cyclotron or synchrotron accelerators. Among this the role of accelerators are important from several perspectives for example, most centers are equipped only with one accelerator (to accelerate only protons, only carbon, or both) so select the type of accelerator always been a key point and challenging one [2].

Since the establishment of centers located in hospitals is growing therefore, using the mentioned accelerator require to consider the clinical centers with high dimensions. On the other hand, unlike traditional radiation therapy, usually accelerator and beam transmission lines with nozzle rotate around the patient, in Hadron therapy techniques due to limitations on size and weight of such equipment yet implemented of this pattern is faced with problems and limitations [22].

In economic terms, the cost of equipping the centers with such accelerator is very high although the choice of dose delivery systems (passive or active) and choice of Gantry and maintenance and repair involved in this issue, but you cannot ignore the key point that the measures that cause reduce size without loss of expectable performance of these machines can partly responsible for the current problems. To reduce weight, size and price approach can be effective in single-room centers [23-24]

The use of superconducting sync-cyclotron due to a significant decrease in size in the last decade is a good candidate for achieving this objective and currently it is taken into consideration.

As superconducting sync-cyclotron for accelerate particles such as 12C6 + and H2 +, respectively, to 400MeV/u and 260MeV/u have been designed. In addition, the ability to accelerate other particles such as 10B5 +, He2 +, 6Li3 + is considered [25-26].

VI. Conclusion

Laser accelerators beam of charged particles with very compact dimensions, is able to provide new methods in hadron therapy. In this type of accelerator, change of energy of the proton beam can be performed easily and quickly and can be achieved easily an accurate beam growing by using a small and spot beam. Now proton beam of laser accelerator as an advanced tool in radiotherapy makes it possible to provide treatment of superficial tumors. Since the reduction in the size, complexity and cost are effective in choice of accelerator, but cannot know a laser accelerator superior than cyclotron accelerator for its properties.

Because it may be preferred using cyclotron accelerator in treatment tumors with harder tissue and in more body depth, but due to the aforementioned accelerator features, there is no doubt that laser accelerator is becoming more common than cyclotron.

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