

EVOLUTION OF RADIOTHERAPY MACHINES AND CHANGING SCENARIO IN INDIA

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HISTORICAL

Two events in the last five years of the nineteenth century revolutionized medical diagnosis and treatment; These were the discovery of X-rays by Roentgen in 1895 and the discovery of radioactivity by Becquerel in 1896, leading to the isolation of radium by the Curies in 1898. X-rays and, to a lesser extent, radium were powerful diagnostic and therapeutic tools in the physicians' hands and they were eagerly exploited. Very soon the biological damage from overexposure to radiation had been observed. X-rays were also used for therapy and the first curing of cancer had been claimed. The only treatment for cancer at that time was surgery, which was risky and so here was a new 'scientific' method to be explored.

TELECURIE UNITS

Because of the success achieved using radium in the treatment of accessible cancers by intracavitary, interstitial and especially mould techniques, the clinicians were anxious to employ the only available source at that time for treatment of cancers in other inaccessible sites hence Radium 226 was used as a teletherapy source.

The first sources of supervoltage radiation were therefore telegamma apparatuses using radium. Because of the limited supply and high cost of radium, these devices never did meet, even in western countries, with widespread use. They had even in their most sophisticated form all the physical disadvantages one could think of- but they did have one great advantage, that of beam quality, which clinicians were quick to recognize.

The early development of radium teletherapy machines with the source at a distance-began in 1919 at the Middlesex Hospital, London with 2.5 g of radium. There were similar developments in Paris, New York and Stockholm. In 1922 Eric Lysholm at the Radium hemmet at Stockholm built a unit with 2 grams of radium at a distance of 6 cm.

This was called a “radium howitzer”(1). Later designs, often called 'radium bombs', were of higher activity (up to 10 g) and could be used with a variety of radiation beam sizes. Radiation protection measures had to be strengthened: in one unit, made by Bryant Symons Ltd, which was standard equipment for treating head and neck cancers from the late 1930s to the 1960s, the source was housed in a separate lead safe several metres from the teletherapy unit, the source travelling between them by pneumatic transfer.

X-ray Units, Van de Graff Units and Betatrons:

In order to improve the depth dose over telerradium units, X-rays of higher voltage was employed. By 1923, an X-ray set operating 200 kV was installed at Guy's Hospital, London, which, although rudimentary, had all the necessary components of a treatment machine: However, the performance of the sealed-off tubes was poor above 170kV, and continuously evacuated tubes were used in Sheffield in 1933, as part of the drive for higher voltage equipment of greater reliability. Although it only operated at 140kV, this was accepted as being sufficiently penetrating to treat fairly superficial tumours, and even though the container was rather unwieldy, it was simple to instal in a medium-sized room. This set was developed in the late 1930s and remained in use until the middle 1950s when the main work-horses of most radiotherapy departments became 250 KV machines (2).

The effectiveness of radiotherapy treatment depends upon maximizing the radiation dose to the tumour while minimizing the dose to all the surrounding normal tissues. As radiotherapy developed, multi-beam techniques, in which radiation is incident upon the tumour from several different directions, were developed. Each beam added radiation dose to the tumour, while spreading the dose received by the normal tissues between the tumour and the surface of the patient. In order to minimize the dose of radiation to normal tissue, therapy sets have also been used with a rotational movement, so that the tube moves in an arc centred on the tumour. This is known as rotational therapy: first implemented in 1915.

The pioneering supervoltage radiotherapy machines began to be installed just before World War II. Notable amongst these were

the Medical Research Council's 500 kV van de Graaff generator at Hammersmith Hospital and the 1 MV continuously evacuated generator at St Bartholomew's Hospital (opened by Rutherford), both built by staff of Metropolitan Vickers Company. In the USA, D. W. Kerst created the betatron in 1940 at the University of Illinois, his original machine accelerating electrons to 2 MeV, but it was not until 1953 that a 'medical' betatron, manufactured by the Allis-Chalmers Company, with appropriate positioning facilities was used at the Sloankettering Memorial Hospital, New York. The objective was to generate more penetrating radiation to give a better depth dose to deep-seated tumours. Betatrons in the energy range from 13 to 45 MeV are in use. The major limitation of the betatron is its low dose rate. The physicists associated with these installations were concerned not only with making these experimental nuclear physics machines work in a clinical environment, which was not an easy task, but also with exploring the changed biological interactions at these considerably higher energies, where the biological effects of a given radiation dose could be expected to be different.

COBALT-60 UNITS:

The advent of the nuclear reactor led to plentiful supplies of artificial radionuclides in the 1950s. Sources of cobalt-60 (with a half-life of 5.26 years, emitting 1.17 and 1.33 MeV radiations, eventually reaching several kilocuries), popularly nicknamed the 'cobalt-bomb', became the work-horse of most radiotherapy departments in the 1960s and 1970s. The first machines contained sources made by Mayneord for neutron irradiation in a reactor, and one of these led to the establishment of telecobalt therapy by Johns in Saskatchewan in 1951. Higher percentage doses at depth are obtained, because of the greater penetration of the beam and also the greater distance between the source and the patient which became possible. Also wedge fields could be used more than at 250 kV: these are achieved by placing in the beam a wedge of absorbing metal, such as copper, to give a much lower radiation intensity on the side of the beam with the greater thickness of copper than on the other side: they were first developed by Miller at Sheffield in 1944 for 200 kV, but at this energy, outputs and depth-dose are too low for them to be truly effective. Wedge fields are of great value in treating tumours in corner sites, e.g. in the head,

when two fields at right angles on the corner give a uniform dose distribution to the tumour, while irradiating very little normal tissue.

War-time radar led to the development of microwave electron linear accelerators which have made possible modern radiotherapy treatments of tumours with megavoltage x-rays. The first one was at Hammersmith Hospital, operating at 8 MV, built by Metropolitan Vickers and installed in 1952. This was an exciting and idealistic time, when scientists and industrialists were anxious to adapt the scientific developments of war to more humane applications. However, with the exception of the leading radiotherapy departments, the Co-60 therapy unit remained the work-horse of most radiotherapy departments until the 1980s, when linear accelerators became much more reliable and versatile in the hostile clinical environment, partly because of computer-controlled systems. This was also a time when the disadvantages of using cobalt-60 became generally appreciated especially the disposal of the radioactive sources beyond their useful life. Most leading hospitals are now equipped with 6-10 MV accelerators, and machines up to 20 MV are now common: these have a selection of energies for the optimum treatment of different depths and sites. Together with the very high-intensity output, the linear electron accelerator has become the machine of choice, such that it is now the work-horse of modern radiotherapy departments, particularly for the treatment of deep-seated tumours.

Many clinical linear accelerators also have the capability of delivering an emergent electron beam in addition to x-ray photons. Electron radiotherapy is believed to be advantageous for some treatments.

PARTICLES FOR RADIOTHERAPY

In the mid-1970s there has been much interest in the possible use of high energy particles in radiotherapy. These particles include neutrons, protons, deuterons, stripped nuclei, and negative mesons (5).

NEUTRONS: Fast neutrons were first used in radiotherapy by Stone in 1938, only six years after the neutron had been discovered. After five years' experience in their use Stone began to see some very severe late effects and came to the conclusion that neutrons were not a useful

particle in radiotherapy. It should be remembered that at this time there was very little information concerning the biological effects of neutrons on tissue, and their mode of action was not understood. There are, however, some logical reasons why neutrons should be a useful form of radiotherapy. For these reasons a new trial was started in 1966 by the group at Hammersmith Hospital, London. Since that time many other trials have started for which the final results are not yet available. The evidence to date suggests, however, that if they have an advantage it is minimal. It should be pointed out that, although intense beams of neutrons are produced in nuclear reactors, these are thermal neutrons and do not have a high enough energy to be useful in radiotherapy. High energy neutron beams can be produced by D-T generators, cyclotrons, or linacs. These machines are expensive, and none is ideal and hence neutron therapy is not in general use now.

PROTONS AND DEUTERONS: High energy charged particles from a linac or cyclotron have properties that may be useful in radiotherapy. 190 MeV deuterons produce an almost constant dose to a depth of about 10 cm. followed by a region of high dose from 10 to 13 cm, after which the dose falls quickly to zero. The high dose at the end of the particle range is called the Bragg peak. These particles have been used in Bewrkely and Harvard for a number of years to treat small inaccessible organs of the body, such as the pituitary gland. They are also being evaluated for more generalized radiotherapy.

STRIPPED NUCLEII: To produce high energy stripped nucleii, the group in Berkeley used their HILAC linear accelerator as a preaccelerator and the betatron as a booster. The two machines are connected by a 500 foot beam transfer line. With such a machine, energies up to 1000 MeV per nucleon are possible. Most of their current experiments are carried out with 9000 MeV neon nucleii (neon has a mass number of 20 so each particle (nucleon) has an energy of about 450 MeV), 6400 MeV oxygen (400 MeV per nucleon), or 3120 MeV carbon nucleii (260 MeV per nucleon). Stripped nucleii produce a very intense Bragg peak and have attractive radiological properties. The production of these high energy particles is a massive undertaking.

MESONS: Beams of negative mesons can be produced in a very large spiral ridge cyclotron or a very large linac. The particles produce

an even more pronounced Bragg peak at the end of their range than do stripped nuclei because a nuclear reaction occurs as the meson disappears. meson beams suffer from low intensity so that one cannot afford to throw away any of the particles in designing the beam transport system. This means complex magnetic systems must be used to collimate the beam into a useful shape. Further, the beams are always contaminated with electrons and neutrons and their effects must be minimized. If a practical system could be designed to control mesons, they might be useful particles since they have some very attractive radiobiological properties. Because of the high capital cost as well as maintenance cost the particle therapy units are not used routinely in many cancer centres.

Radiotherapy - Indian Scenario

The evolution of radiotherapy in India has mostly followed the western pattern in general, since we are still depending on the imported machines. In the early 50's only deep X-ray units operating in the 200 - 400 kV range were available for teletherapy; the quality and the depth dose of these units were very poor. Of course the radium sources were used extensively for brachytherapy in most of the centres in India. The first cobalt-60 teletherapy unit (Eldorado A) was commissioned at the Cancer Institute, Chennai-600 020 in 1956 and soon many others followed in the country. Today there are about 290 cobalt units spread over 180 centres in different parts of India(4). In addition there are also about 10 telecaesium units operating in the various centres. The betatrons and the 2 MV Van de Graff generators never came in a big way as expected because of their undependability and high cost. The caesium units were never popular because of their unfavourable physical characteristics for teletherapy. The linear accelerators took a little longer to arrive on the Indian scene; the first linear accelerator was installed at the Cancer Institute, Chennai-20 in 1976. Now there are 35 linear accelerators operating in some of the major cancer centres in the various parts of India. Most of these accelerators are in the energy range of 6-15 MV capable of both X-rays and electron therapy.

Few attempts at indigenous development of teletherapy units were made but have not been really successful to fulfil the needs of the country. Cancer Institute, Chennai developed first telecaesium

unit in collaboration with Atomic Energy Establishment, Trombay (AEET) in 1962 (3). The International General Electric Company developed a cobalt-60 teletherapy unit (Gammarex) in 1970's but discontinued manufacture after some years probably due to some technical problem. Cancer Institute made another attempt in the 1990's to develop a cobalt unit but had to be discontinued due to lack of financial support. The BARC is now making another attempt to develop a cobalt-60 unit. Attempts have been made by Sameer (Society for Applied Microwave Electronics Engineering and Research) who have developed an indigenous 4 MV medical linear accelerator. 2 or 3 units have been installed. Further attempts are now being made to develop an integrated medical linac system with 6 MV energy under the national programme for deployment of indigenously developed integrated medical LINAC for cancer therapy a proposal under Jai Vigyan National Science and Technology Mission.

It appears as though the country will still depend on imported units both for cobalt-60 teletherapy and linear accelerators which will be the most preferred units for radiotherapy in our country. The linear accelerators in the energy range of 6 to 10 MV will be able to handle a good load of patients and one cobalt unit in every major centre will be a useful machine, especially for calibration purposes due to its predictable dose rate.

References

1. 'The supervoltage story' M.D. Schulz The American Journal of Roentgenology, Radium Therapy and Nuclear Medicine, No.4, Vol.124, 1975 PP. 541-559.
2. Twentieth Century Physics Ch.25. Medical Physics by J.R.Mallard, Pages: 1855 1941, 1996
3. Indigenisation of treatment aids/equipments in Radiotherapy-Chapter 6. A.V.Lakshmanan, I.S.Balakrishnan and B.K.Bhaskar. PP 49-56, Advances in Medical Physics, ED. MM. Rehani, Jaypee Brothers, New Delhi, 2000.
4. Data on teletherapy units in India - Personal communication BARC, August 2001. High Energy Machines Chapter 4, The Physics of Radiology-4th edition by H.E.Johns. PP: 102-13.