A GEOMETRICAL AND EXPLORATORY TESTAMENT OF THE DOSE AT THE CENTRAL RAY OF THE DIVERGING GAMMA RADIATION BEAM USED IN RADIOTHERAPY

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Abstract: The foremost intention of the study is to reaffirm the relevance of the phenomenon that the dose at the central ray of a diverging Gamma radiation beam used in Radiotherapy is maximum. This study has been conducted in an all together different dimension - mathematical dimension using Pythagoras Theorem and Inverse Square law. After experimentation and thorough analysis, it has been found that the assumption is valid from a mathematical perspective.

Keywords: radiotherapy; gamma radiation beam; isocentre; Pythagoras theorem; Inverse square law

1. Introduction:

Radiotherapy is the branch of medicine which uses ionizing radiations to destroy cancer cells. Radionuclide sources with high activity and high energy is required for the treatment purpose apart from X-Ray photons of various energies and other particulate radiations. Cobalt 60 doubly sealed sources is a time tested radionuclide with a half life of 5.27 years [1, 2]. It is an artificially produced isotope from Cobalt 59 by neutron activation in nuclear reactors. Cobalt 60 decays to unstable Nickel 60 radioisotope by the process of negative beta decay [1, 2], a beauty of weak force. The unstable Nickel 60 nucleus attains stability by emitting two gamma photons having energy 1.17 MeV and 1.33 MeV respectively [1, 2]. The overall nuclear reaction can be written as: ${}^{59}_{27}Co + {}^{1}_{0}n \rightarrow {}^{60}_{27}Co^{*} \rightarrow {}^{60}_{28}Ni + e^{-} + 2\,\gamma\,photons$. The modern Teletherapy Cobalt units are extensively used in most of the developing nations. The diverging radiation coming out of the source carries energy into the exposed medium [3]. The actual prediction of the energy distribution is indeed a very complex process and depends on many parameters, various experiments and many mathematical techniques [3]. Since the relationship between the central ray and rays on the periphery of the radiation beam cannot be interpreted in a simplified manner because of the 3D clinical situation which in turn is influenced by host of other factors, so it becomes imperative to analyze it from a 2D perspective [3, 4]. On the basis of this, the study is carried out which in turn crops the possibility of complication created if scattered rays are taken into consideration. A thought experiment is then carried out to show that the central ray has the maximum intensity by using mathematical tools. Such a process is chosen in order to arrive at an ideal conclusion that would not only explain the phenomenon in an abstract manner but also in a simplified way. An experiment has also been designed to supplement the analysis.

2. Mathematical description:

The gamma radiation coming out of the Cobalt 60 radioisotope is a 3D process in the form of a cone as shown in the Figure 1. In Irradiation therapy with ionizing radiation, the central ray of a diverging gamma radiation beam coming out of a Cobalt 60 radioisotope has the maximum dose. When the Telecobalt machine is used, isocentre is chosen as the point of maximum dose. Because of the too comprehensive explanation, a simplified option had to be chalked out. Hence an attempt was made to study the concept in a simpler manner.

Figure 1: The figure taken from internet showing that the radiation beam coming out of the source follows a conical shape. It is just a schematic representation.

A thought experiment was considered to rejustify the above concept. In this experiment, a person named 'Curie' with the supernatural power of visualizing the invisible gamma radiation and absolutely free from radiation hazard is standing in the treatment room her location is directly opposite to the gantry. Her eyes are fixed on the source and she is asked to describe the gamma rays emerging from the source. According to Curie, an equilateral triangular shape of diverging radiation beam is visible as she stands face to face with the source as shown in the Figure 2.

Figure 2: The BHABHATRON II machine at SCI, GMC showing the Gantry and Couch and the picture on the right represents our thought experiment showing Curie's vision.

This visual figure is taken as the abstract specimen for analysis. The equilateral triangle thus derived from the specimen image is divided into halves forming two equal right angled triangles as shown in the Figure 3. The premise of equilateral triangle can be further validated if one considers the machine setup. The beam emitting from the machine takes a square shape on the couch with the help of collimators. The square is divided into four quadrants by applying 2D orthogonal Cartesian coordinate system i.e. XY-Coordinate system.

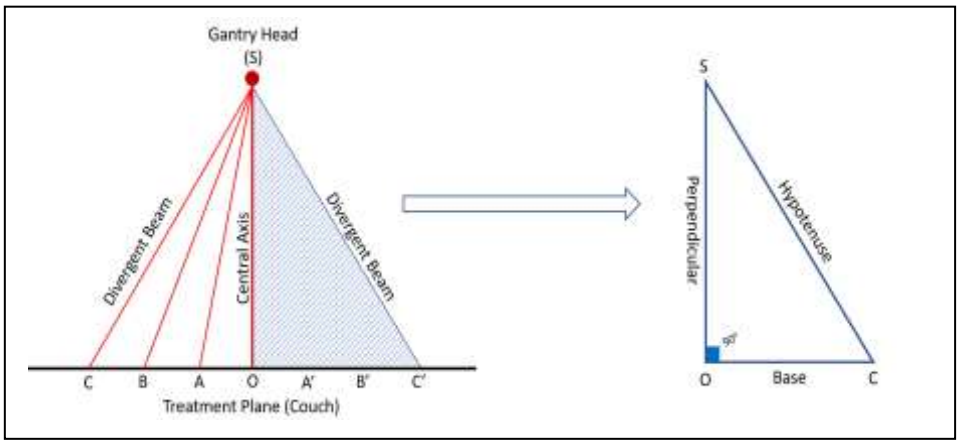

Figure 3: The above figure represents our mathematical concept based on our analysis.

It has been observed that the end points of the abscissa or the ordinates of the square coincide with the vertices of the equilateral triangle. Hence, establishing the symmetry of the square and the equilateral triangle with respect to the origin of the XY-Coordinate system. Then, the third vertex of the equilateral triangle is joined to the origin by a straight line; the given triangle is divided into two right angled triangles with a common perpendicular. Herein comes the application of Pythagoras theorem as shown in Figure 3.

The radioactive source has been considered as a point source in order to get the benefits of Inverse square law which states that the intensity is maximum when the distance from the source to the measurement point is shortest, means dose is maximum. The diverging beam from the point source was considered as a right angled triangle and the perpendicular of a right angled triangle is always shorter than the hypotenuse as per Pythagoras theorem. By considering the perpendicular of the right angled triangle as the central ray, it has been shown that it receives the maximum dose using the concept of Inverse square law [3]. This has also been illustrated experimentally using a Farmer type ion chamber in Bhabhatron II teletherapy machine.

3. Experimental details:

The Cobalt 60 Teletherapy machine – Bhabhatron – II, a calibrated PTW-Freiburg's Farmer type ion chamber of 0.6 cc and a UNIDOSE E Electrometer has been used for the experiment as shown in Figure 4. The Bhabhatron II machine's Gantry, collimator and couch were kept at zero degree. The ion chamber with buildup cap was placed on the couch over a graph paper. The graph paper was used to follow the Cartesian coordinate system for the proper placement of the ion chamber. A $30 \times 30\ cm^2$ field was drawn in the graph paper and the origin "O" on the graph paper was considered as the isocentre or the central ray when matched with the $30 \times 30\ cm^2$ Gamma radiation field. Three markings A, B, C and A^1, B^1, C^1 has been put on the either side of the origin "O", 5 cm apart.

Figure 4: The figure on the left is the PTW-Freiburg's Farmer type ion chamber of 0.6 cc and on the right is the UNIDOSE E Electrometer.

The sensitive volume of the ion chamber which was placed on the graph paper was aligned with the central ray of the gamma beam. The source to the surface distance (SSD) was kept at 80 cm, with the radiation field size set at $30 \times 30\ cm^2$ matching with the area drawn in the graph paper. The entire setup was verified using laser beams in the treatment room. The electrometer was kept at the control console and was connected to the ion chamber by a wire through the conduit on the wall between the two rooms. When the ion chamber was

irradiated by the gamma radiation beam, the electrometer readings were noted. The entire setup and the isocentre have been kept fixed and the electrometer readings were noted by placing the ion chamber in all the marked positions on the graph paper which has been shown in the Table 1. From the experimental data it is revealed that the dose at point "O" i.e. the isocentre or the central ray is maximum as shown in Figure 5. Hence, validates the mathematical concepts used in this study.

Table 1: Experimental readings obtained using an ion chamber and electrometer in Bhabhatron II.

Various positions on the graph paper	1st Reading (nC)	2nd Reading (nC)	3rd Reading (nC)	Average Reading (nC)
C	15.99	16.12	16.21	16.11
B	24.22	24.42	24.37	24.34
A	29.64	29.61	29.76	29.67
O- Central ray	**32.92**	**32.95**	**32.94**	**32.94**
A^1	29.34	29.56	29.66	29.52
B^1	23.74	23.98	24.07	23.93
C^1	16.42	16.39	15.97	16.26

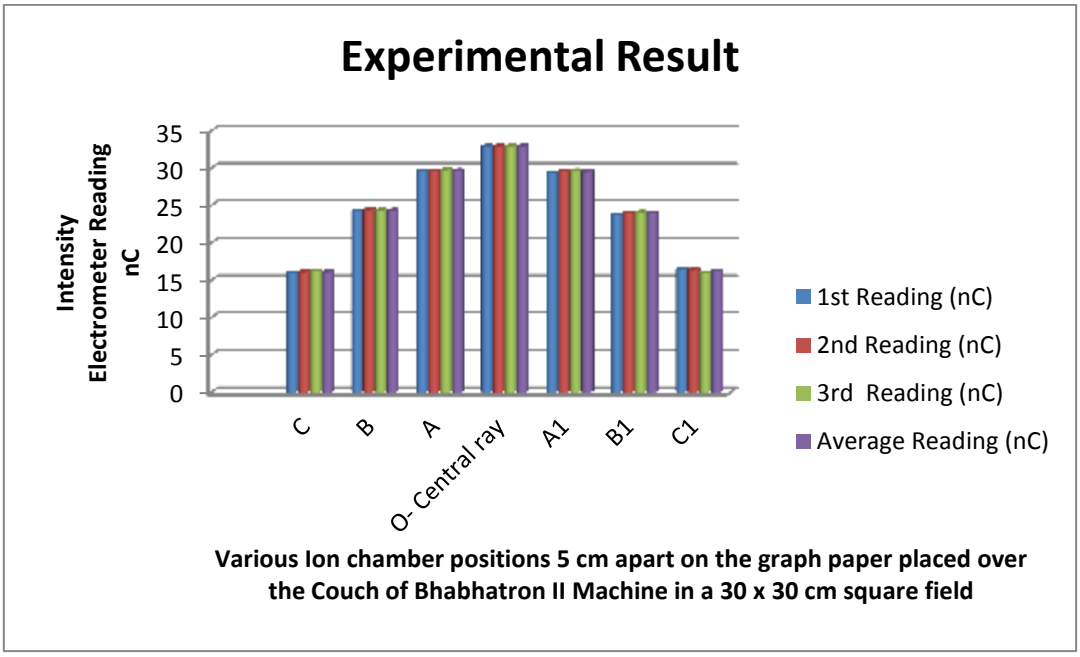

Figure 5: The experimental validation of the mathematical concept.

4. Result:

The experimental readings revealed that the intensity at the central ray is more than the other portions of the diverging radiation beam which is in complete agreement with the methods shown mathematically. Thus,

$$Dose\ at\ C < Dose\ at\ B < Dose\ at\ A < Dose\ at\ \mathrm{O} > Dose\ at\ A^1 > Dose\ at\ B^1 > Dose\ at\ C^1$$

5. Conclusion:

This study revealed a simple and abstract way of calculating dose at the central ray and the dose off the central ray. Hence in accordance with the thought experiment, the radiation beam emitting from the cobalt 60 teletherapy sources is more at the centre than at the periphery.

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