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COMPARATIVE ANALYSIS OF LINAC RADIO-BUNKER THERAPY VS. PROTON THERAPY FOR THE TREATMENT OF HEAD AND NECK CANCER

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ABSTRACT

This study aims to provide a comparative analysis of the performance of LINAC and Proton Therapy for head and neck cancer. The study analyzes precision, effect on surrounding organs, side effects, quality of patient life, cost, and technology accessibility. The results indicate the better efficiency of Proton Therapy with a few counterpoints discussed in the paper. The paper also expands on the recent developments in both technologies and stresses the increase in the use of Proton Therapy worldwide.

KEYWORDS: LINAC, Proton Therapy, Cancer, Head and Neck Cancer, Reflexion System, Homogeneity

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THESIS STATEMENT

Despite being costly and having low patient volume, Proton Therapy is more efficient than LINAC for treating head and neck cancer due to its precision, less damage to surrounding tissues, and fewer side effects on the patient.

INTRODUCTION

Radiation Therapy has been one of the most efficient ways of treating cancer, allowing for improved quality of life for cancer patients. Concerningly, global trends indicate an increase in the number of cancer cases worldwide. 20 million new cancer cases were projected in 2024, with head and neck cancer contributing significantly to the burden. This brings a pressing question to light: what is the most efficient treatment in radiation therapy? The purpose of this paper is to provide a comparative analysis between LINAC and Proton Therapy (PT), two leading radiation therapies for treating head and neck cancer (HNC), by comparing factors like accuracy, effect on normal tissues, side effects, cost, and accessibility. The paper brings awareness to the need to increase the use of proton therapy and also expands on the significant advancements made in both LINAC and Proton Therapy (PT). This study combines the use of primary and secondary sources to elaborate on the objectives.

LITERATURE REVIEW

In this paper, the literature is structured to provide experimental evidence, quantitative data, and qualitative context. For example, the investigation by Resto et al. (2008) involving 102 patients that showed the success of PT in treating HNC; the study provided evidence that high-dose radiotherapy with proton beams resulted in excellent control rates for advanced sino-nasal cancer. However, even after providing evidence of the success of PT, the study does not compare PT to other methods of radiation like the LINAC; this is the gap this paper aims to fill.

The study by Dr. Baumann and his colleagues analyzed the data of 1500 adults receiving chemotherapy and radiation between 2011 and 2016, where 400 patients received PT while the others received traditional radiation. The study revealed that the patients treated by PT had fewer side effects as compared to patients receiving traditional radiation. However, certain limitations of the paper, such as fewer people with head and neck cancer who are most likely to suffer from radiation-associated side effects, were included in the study. The paper also included patients from "privileged" backgrounds, and socio-economic status was not taken up as a factor to compare the methods, which is covered by this paper.

The study by Makishima et al. (2015) gave a comparison between Proton Therapy and X-ray chemoradiotherapy for esophageal cancer. It utilized adaptive dose-volume histogram analysis to assess the impact of treatment on surrounding healthy tissue. The study concluded with Proton Therapy resulting in fewer adverse effects compared to X-rays. However, the comparative analysis was only done with one factor, while this paper presents qualitative and quantitative factors while comparing Proton Therapy to LINAC, which is more efficient than X-ray chemoradiotherapy.

The paper also explores literature from Cancer Research UK regarding the effect of head and neck radiotherapy and how it impacts patient health to specifically analyze which form of therapy would suit best to improve patient life. It also includes overviews from the National Cancer Institute (2019) on the various forms of radiation therapy and treatment planning for maximum efficiency. A subsequent update from the same institute (2020) addresses the benefits of Proton Therapy. The paper also explores advancements in Proton Therapy and LINAC taking into account sources like Karzmark (1984). The paper combines previous research works and comments by experts at Cytecare Hospital to bring out the overall comparison and analysis between the LINAC and PT.

METHODOLOGY

This paper employs a secondary research approach that combines qualitative and quantitative analysis in a hybrid mode. This methodology suits the research objective as it enables a comprehensive evaluation of primary research and experimental surveys done with respect to LINAC and PT. By combining quantitative data with qualitative insights, the study aims to provide a thorough comparison and an overall understanding to evaluate an efficient method to administer radiation therapy. The hybrid mode ensures balanced analysis with data and contextual factors, leading to realistic and nuanced conclusions.

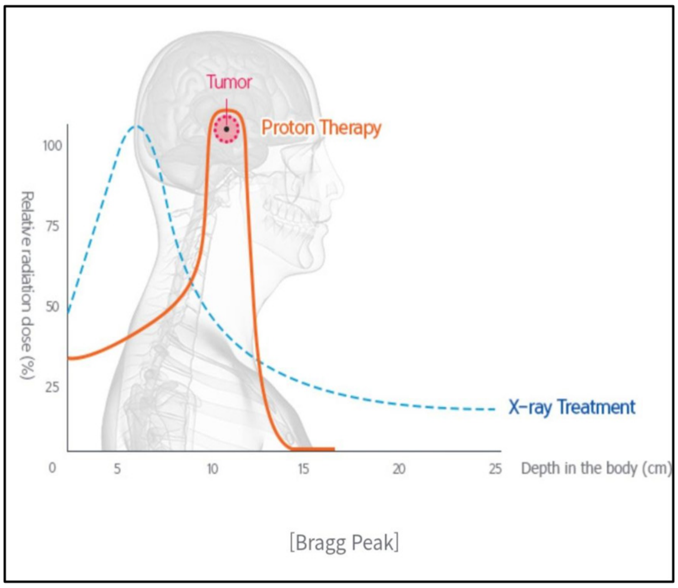
RESULTS & ANALYSIS

1. Accuracy

(A) Conformity Index

LINAC is a device that uses high-energy X-rays, or electrons, to treat cancer. The device accelerates electrons to produce high-energy beams directed towards a mapped tumor site. The LINAC is capable of mapping and generating the shape of the tumor to minimize damage. However, the beams still damage a certain area of surrounding tissue, especially the ones located on the dorsal side of the tumor. Some of the radiation energy is absorbed by normal organs.

In the case of PT, the proton energy is accelerated to a point where the energy is sufficient to reach the distal edge of the tumor with the help of cyclotrons and synchrotrons. The Bragg Peak property of the proton allows it to penetrate through normal tissues, release the maximum amount of energy at the end of the beam at the target location, and disappear instantly instead of being absorbed by the surrounding tissues.



Source: Journal of Korean Neurosurgical Society (2018)

Figure 1: Comparison of Precision of PT and LINAC

In the case of HNC, qualitatively, the most efficient system should have high accuracy and minimum damage to surrounding tissue due to the presence of vital organs like the brain. Quantitatively, an investigation by Resto et al. (2008) involving 102 patients showed the success of PT in treating HNC. The basic rubric of comparison that can be taken is the Conformity Index (CI)*.

*CI is the best rubric to use for this comparison as it provides a range within which the true effect size lies, offering a more reliable estimate than a mean estimate, and its statistical value is also significant as it provides insight into the magnitude of the difference between the two treatments.

As per the summarized data from various clinical studies:
CI = Tv * Ptv
Here, Conformity Index (CI) = Treated volume (Tv) * Planned target volume (Pv)

*Conformity Index also measures how well the radiation dose conforms to the target volume; the CI measured above is in regard to the severity on a scale from 0-10

For LINAC:
Average CI = 1.2
Standard deviation = 0.1

For Proton Therapy:
Average CI = 1.1
Standard deviation = 0.05

A P-value of <0.05 suggests that Proton Therapy has a better CI than LINAC, making it considerably more accurate and effective for treating delicate structures such as the HNC.
An ideal CI value is close to 1, this indicates that the radiation dose perfectly matches the shape of the target.

(B) Homogeneity Index

Another way of measuring accuracy is through the Homogeneity Index (HI) to assess the uniformity of the radiation dose within the tumor. Proton Therapy is known for its ability to deliver a localized dose to the tumor via the Bragg peak property and most of the proton energy is confined to a certain area at a certain depth, which allows a sharp dose drop to reduce dosage to surrounding healthy tissues. This sharp-dose gradient can lead to challenges in maintaining homogeneity.

In the case of LINAC, the high energy X-rays do not have Bragg Peak and the dose distribution is spread out, which may maintain homogeneity but puts surrounding healthy tissues at risk. However, in the case of PT, the homogeneity index is good for uniform tissues but requires strategic treatment planning for heterogeneous regions. This puts PT at a higher standing, as risking damage to surrounding healthy tissues in LINAC is not a good trade-off for homogeneity index.

2. Dose to Organs at Risk and Side Effects

Due to the Bragg Peak property of the proton, the damage to surrounding tissues is significantly less as compared to LINAC. By using the NTCP (normal tissue complication probability) specifically for HNC, we get the following data:

Using the Lyman-Kutcher-Burman (LKB) model:

$$NTCP = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} e^{-t^2/2}\, dt$$

where

$$t = \frac{D - D_{50}}{m \cdot D_{50}}$$

Source: National Library of Medicine (2023)

Figure 2: Explanation of the Lyman-Kutcher-Burman Model

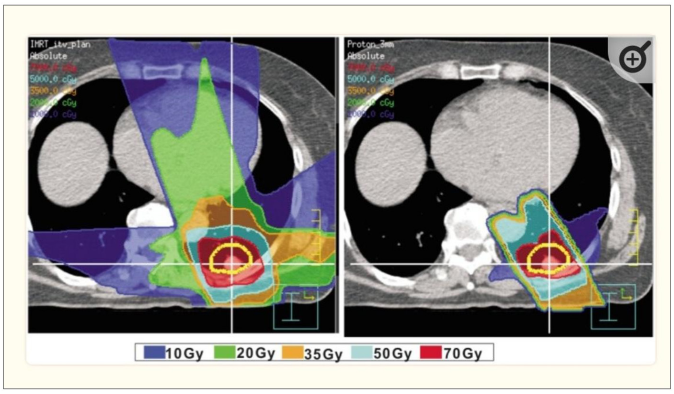
For LINAC:
Dose - 60 Gy
D50 - 65 Gy
m - 0.35 Gy

For Proton Therapy:
Dose - 45 Gy
D50 - 65 Gy
m - 0.35 Gy

Result:
LINAC NTCP = 41.3%
Proton Therapy NTCP = 18.9%

PT has a lower NTCP for HNC, demonstrating lower risks to surrounding structures, thereby making it more efficient for treatment.

*Gray (Gy) unit of ionizing radiation dose is defined as the absorption of one joule of radiation energy per kilogram of matter.
* (m) = mean or average dosage absorbed by a specific area or tissue.



Source: Physics in Medicine and Biology, Pubmed (2003)

Figure 3: Comparison of the effects of therapy on surrounding organs by LINAC (left) and Proton Therapy (right)

With lower NTCP, this also decreases the level of side effects and increases the quality of life of the patient. The side effects of HNC treatment can be quite jarring, ranging from lymphoedema to issues with swallowing and speaking. A study done by Dr. Baumann and his colleagues analyzed the data of 1500 adults receiving chemotherapy and radiation between 2011 and 2016. 400 patients who received PT experienced fewer serious side effects as compared to traditional X-rays. PT also did not hinder a patient's ability to perform routine activities as much as traditional radiation.

3. Cost and Setup

The LINAC equipment costs approximately $1-2.5 million (Rs.10-25 crore), with additional costs of installation, infrastructure, and maintenance. Additionally, the LINAC requires a bunker design to allow the safe escape of radiation.

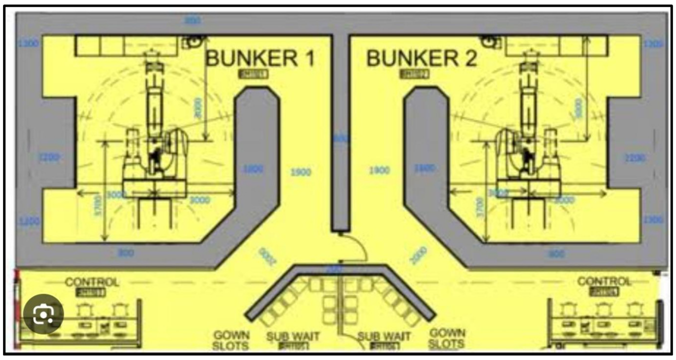


Figure 4: Radio Bunker Therapy Design

The LINAC also receives high patient volume due to its cost-effectiveness and accessibility. Compared to the LINAC, the PT is considerably more expensive, with its equipment costing $35–59 million (Rs. 300–500 crore), not counting additional costs. The PT also has comparatively high electricity usage and requires an expert team to operate it. This is the primary reason for the low volume of patients for the PT. However, considering its significance and efficiency compared to traditional rays, PT should ideally be used more for cancer treatments, especially for HNC, which has many vital organs at risk.

4. Advancements

The most recent advancement to the LINAC is the Reflexion System, approved in 2021, which utilizes PET scanners in the integrated image guidance system to give better accuracy when treating patients. A specific advancement in PT for HNC is the use of pencil beam scanning to treat tumors with unparalleled precision. The technique adds a field mirroring the tumor's shape, and the beam can be released with the precision of a few millimeters (the width of a pencil). This advancement is very significant in treating complex cancers like HNC.

CONCLUSION

Proton therapy is a far more efficient way to treat HNC in terms of its precision, side effects, and effect on surrounding tissues. Cost and accessibility are certain disadvantages to the efficiency of the PT. However, it is a leader in its technological efficiency and the quality of life that it provides to the patient. It is estimated that the investment will provide a far greater output than the commonly used LINAC. Advancements in PT, such as the pencil beam scanning technique, add to its efficiency. PT should be further advocated for HNC and other complex cancer treatments.

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