Journal of Radiation and Nuclear Applications
An International Journal

http://dx.doi.org/10.18576/jrna/100202

Evaluation of Dosimetric Parameters for Flattening Filter Free Photon Beams in Radiotherapy for Two Recent Linear Accelerator Machines

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Received: 10 Mar. 2025, Revised: 17 Mar. 2025, Accepted: 24 Mar. 2025.
Published online: 1 May 2025.

Abstract: radiation to target and destroy malignant cells. Linear accelerators (linacs) have greatly improved this field, allowing for precise delivery of radiation doses to tumors while minimizing exposure to surrounding healthy tissues. Flattening filter-free (FFF) beams have emerged as a significant development in Linac technology, providing unique dosimetric advantages and improving treatment efficiency. Flattening filters, traditionally used in linear accelerators, help to create a uniform dose distribution across the radiation beam**.** Aim of the Work The dosimetric study was conducted using Varian True Beam and Elekta Versa HD linear accelerators, evaluating FFF photon beams at energies of 6 MV and 10 MV**.** Materials and Methods Measurements included :Percentage Depth Dose, Beam Output Factor, Beam Profiles and Dose Rate Results and Discussions The study found significant differences in dose distribution and clinical implications between the two systems :PDD Curves: Higher energy (10 MV) beams delivered greater doses at deeper tissue levels compared to 6 MV, enhancing clinical outcomes for deeper tumors .Field Size Influence: Larger field sizes improved dose delivery, with the 10 MV FFF beams showing better coverage for larger tumors. Surface Dose Trends: 6 MV FFF beams demonstrated higher surface doses, making them more effective for superficial tumors. Conclusions: The findings underscore the importance of tailored treatment planning based on dosimetric characteristics, energy selection, and machine performance. Clinicians are advised to consider these factors to optimize patient outcomes while minimizing exposure to healthy tissues.

Keywords: Energy Flattening Filter free, Dosimetric parameters, Linear accelerator.

1 Introduction.

Overview of Linear Accelerators. Varian True-Beam Linear Accelerator The Varian True-Beam linear accelerator is designed to deliver high-quality radiation therapy treatments with advanced imaging capabilities. It supports multiple treatment modalities, including 3D conformal therapy, intensity-modulated radiation therapy (IMRT), and image-guided radiation therapy (IGRT). The True Beam's FFF beam options provide high dose rates, enhancing workflow efficiency, especially for hypo-fractionated regimes [1].

One of the key features of True Beam is its ability to perform rapid dose delivery with minimal treatment times. The system utilizes advanced motion management technologies to accommodate patient movements during treatment, ensuring precise dose delivery even in dynamic situations. Additionally, the True Beam platform is equipped with sophisticated imaging tools, allowing for real-time verification of patient positioning and tumor localization [2,3].

Elekta Versa HD Linear Accelerator The Elekta Versa HD linear accelerator is another state-of-the-art system that offers a range of treatment options, including IMRT, volumetric modulated arc therapy (VMAT), and SBRT. The Versa HD is designed to provide high-quality treatment with enhanced precision and speed. Like True Beam, it also features FFF beam options, which support rapid treatment delivery and improved dose distribution. Versa HD's design emphasizes flexibility and adaptability, allowing for various treatment techniques [5,6].

Standard medical electron linear accelerators (linacs) have

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been used in cancer treatment for the past 6 decades, using both conventional and advanced techniques. Flattening filters are typically used to convert the forward peaked MeV bremsstrahlung photon intensity into a uniform intensity pattern for clinically acceptable beam profiles. [7,8] The dosimetric parameters of unflattened beams differ from flattened beams, as the flattening filter acts as an attenuator, and beam hardener, and is scattered in a standard linac.

Fogliata et al. proposed new definitions for evaluating the beam characteristics of unflattened photon beams and suggested modifications to the dosimetry quality control parameters. As of now, there is no standard acceptance test protocol containing easily implementable definitions of dosimetry parameters for unflat photon beams generated by standard medical linacs. [9,10] The Atomic Energy Regulatory Board (AERB) of India constituted a Task Group to recommend acceptance criteria for flattening filter-free (FFF) photon beams. The Task Group approached manufacturers/suppliers of standard medical linacs for technical details about the technology of their FFF beam linac and their viewpoints in evaluating the characteristics of FFF photon beams. The information received from the manufacturers/suppliers, as well as the data available in the literature, were thoroughly reviewed to evolve acceptance criteria for FFF photon beams from standard medical linacs. [11,12]

Aims of the study:- compare the performance of FFF energies in two prominent linear accelerators: the Varian True Beam and the Elekta Versa HD. By examining their dosimetric characteristics, treatment delivery efficiencies, and clinical implications

2 Experimental Section

This was a retrospective Dosimetric study conducted at our institution. The study included two state-of-the-art linear accelerator machines: Varian True Beam (Varian Medical Systems, Palo Alto, CA, USA) and Elekta Versa HD (Elekta AB, Stockholm, Sweden). Both machines were equipped with the capability to deliver FFF photon beams. Beam Energies and Configurations: The study evaluated the following photon beam energies for each machine:

-Varian TrueBeam: 6 FFF and 10 FFF
-Elekta Versa HD: 6 FFF and 10 FFF

For each beam energy, the following beam configurations were assessed:

-Field sizes: 2 x 2 cm², 10 x 10 cm², and 20 x 20 cm²
-Depths: dmax, 5 cm, 10 cm and 20 cm

Dosimetric Measurements:

Dosimetric measurements were performed using a calibrated water phantom system (PTW, Germany) and a PinPoint chamber ionization chamber The following parameters were evaluated:

1 .Percentage Depth Dose (PDD)
- PDD values were measured at the specified field sizes and depths for each beam energy.

2 .Beam Output Factor (BOF)
- BOF was measured as the ratio of the absorbed dose at the reference field size (10 x 10 cm²) to the absorbed dose at each field size.

3 .Beam Profiles:
- Beam profiles were measured at the specified field sizes and depths for each beam energy.
- Profiles were evaluated for symmetry, flatness, and penumbra.

4 .Dose Rate:
- The maximum dose rate for each beam energy was recorded.

Data Analysis:
The measured dosimetric parameters were analyzed and compared between the Varian TrueBeam and Elekta Versa HD linear accelerators. Statistical analysis was performed using appropriate methods, such as t-tests or ANOVA, to determine the significance of any observed differences.

3 Results and Discussion

3.1 Profile Characteristics

Dose Distribution

-Elekta Linear Accelerator:
- The dose profile typically shows a sharper penumbra, indicating a more defined transition between the high-dose region and the low-dose region.

- The central axis dose (CAX) is often higher, reflecting the machine's efficiency in delivering radiation to the target area.

-Varian Linear Accelerator:
- The dose profile may present a broader penumbra compared to the Elekta, suggesting a gradual transition from the high-dose region to the low-dose region.

- The CAX might also show a high dose, but with a different distribution pattern, which could influence the surrounding healthy tissue exposure. As shown in Fig. 1

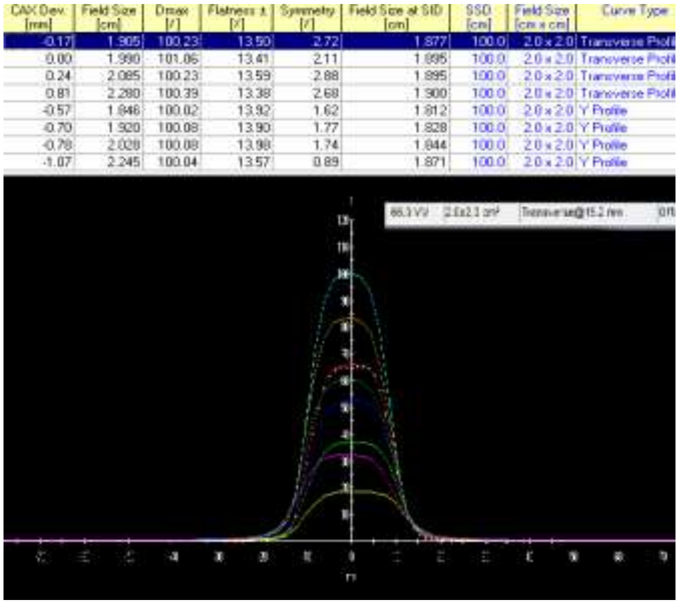

Fig. 1. Field Size 2x2 cm Profiles for Varian Linear and Elekta Accelerators.

Penumbra Width

-Elekta:

- A narrower penumbra width can lead to improved targeting of the tumor while sparing adjacent healthy tissues. This is particularly beneficial in treatments requiring precision, such as stereotactic body radiotherapy (SBRT).

-Varian:

- A wider penumbra may result in an increased dose to surrounding tissues, which could be a concern in treatments where normal tissue sparing is critical. However, this might be balanced by other factors such as dose rate and treatment time.

Clinical Implications

1 .Treatment Planning:

- The differences in dose profiles necessitate tailored treatment planning for each machine. Clinicians must consider these variations when designing treatment plans to optimize tumor coverage while minimizing exposure to healthy tissues.

2 .Quality Assurance:

- Regular QA checks are essential to ensure that the dose profiles remain consistent with the expected characteristics. Variations in the profiles could indicate potential issues with machine calibration or performance.

3 .Patient Outcomes:

Understanding the dosimetric differences can help predict clinical outcomes, such as tumor control rates and the likelihood of radiation-induced side effects. A machine with a sharper penumbra may provide better local control of the tumor while reducing complications.

- The comparison of 2x2 cm field size profiles from Elekta and Varian linear accelerators reveals important differences in dose distribution, penumbra width, and central axis dose. These factors play a significant role in treatment planning and patient safety. Continued research and evaluation of these profiles are essential for optimizing the use of each machine in clinical practice, ensuring that patients receive the most effective and safe radiation therapy possible.

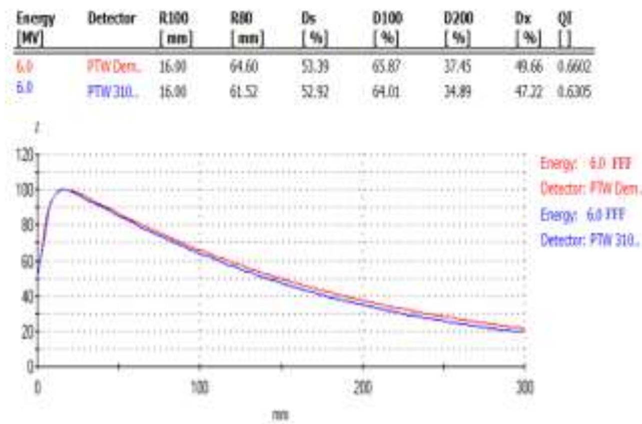

Fig. 2. PDD Curves 6 MV FFF Energies for both linear accelerators.

Table (1): comparison between different dosimetric parameters for both linear accelerators for 6 and 10 MV FFF energies.

Item	True Beam		Versa HD	
	6MV FFF	10 MVFFF	6MV FFF	10 MVFFF
D_{max}	16mm	24	16mm	24
$\%D_S$	53.39%	42.47	52.92%	44.37
$\%DD_{10cm}$	65.87%	72.1	64.01	70.9
$\%DD_{20cm}$	37.45%	43.7	34.89%	42.9

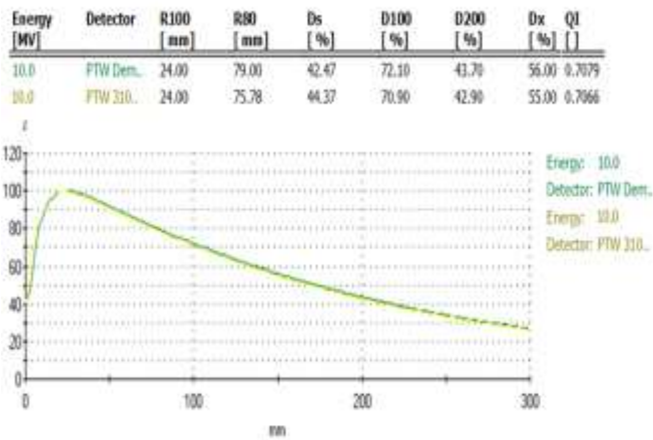

Fig. 3. PDD Curves 10 MV FFF Energies for both linear accelerators**.**

Discussion on PDD Curves for 6 MV FFF and 10 MV FFF Energies

-as shown in both Figs 2 and 3 present a comparison of Percentage Depth Dose (PDD) curves for 6 MV and 10 MV flattening filter-free (FFF) beams at different field sizes. Analyzing these curves is crucial for understanding how varying energies and field sizes affect dose distribution in radiation therapy.

- Energy Comparison

1 .-Dose Distribution Characteristics:

- The PDD curves for both 6 MV and 10 MV FFF beams indicate that higher energy (10 MV) generally results in greater dose delivery at deeper tissue levels compared to the 6 MV beam. This is particularly evident in the PDD curves, where the 10 MV FFF beam shows a more pronounced increase in dose with depth.

2 .Clinical Implications:

- The higher dose delivery at depth for the 10 MV FFF beam makes it preferable for treating deeper tumors, as it allows for effective tumor control while potentially sparing surrounding healthy tissues. This characteristic is essential in treatment planning, especially for patients with tumors located deeper within the body.

Field Size Influence

1 .Impact of Field Size on PDD:

- Both energy levels demonstrate an increase in dose as field size increases. The curves indicate that larger fields enhance the dose delivered to deeper tissues, which is important when planning radiation treatments for larger tumors.
- The differences in slopes between the two energies highlight that the 10 MV FFF beam may provide a more efficient dose distribution as field size increases, leading to better coverage of the tumor volume.

2-Comparison of PDD at Different Depths:

- The PDD curves at 10 cm (PDD10) and 20 cm (PDD20) depths reveal that the dose difference between 6 MV and 10 MV FFF beams becomes more pronounced with increased depth, emphasizing the importance of selecting the appropriate energy based on tumor location.

Practical Considerations

1 .Treatment Planning and Optimization

- Understanding the PDD curves allows clinicians to tailor treatment plans based on individual patient needs. For superficial tumors, the 6 MV FFF beam may be adequate, while for deeper lesions, the 10 MV FFF beam provides better dose coverage.
- Additionally, the reduced scatter and sharper dose gradients associated with FFF beams enhance the ability to spare healthy tissue, further supporting the use of higher energy beams in suitable cases.

2 .Importance of Accurate Measurements:

- Accurate measurement of PDD is critical for effective treatment planning. Variations in field size and energy must be carefully considered to ensure optimal dose distribution and patient safety.

The comparison of PDD curves for 6 MV and 10 MV FFF beams illustrates significant differences in dose distribution characteristics that are vital for effective radiation therapy. The ability of the 10 MV FFF beam to deliver higher doses at greater depths highlights its importance in treating deeper tumors, while the impact of field size on dose delivery further underscores the need for tailored treatment planning. Continued evaluation of these curves will enhance the efficacy of radiation therapy and improve patient outcomes.

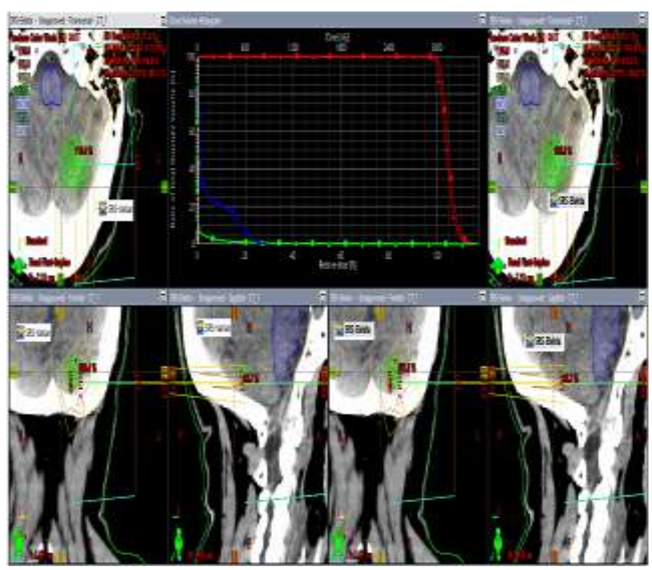

Fig.4. for both plans Rt. For Varian and Lt. for Elekta 6FFF MeV.

As shown in Fig .4 for the SBRT plan for brain tumors using 6MV FFF there is no significant difference between both plans.

3.3 Discussion on PDD for 10 cm Depth for 6 MV FFF and 10 MV FFF Beams

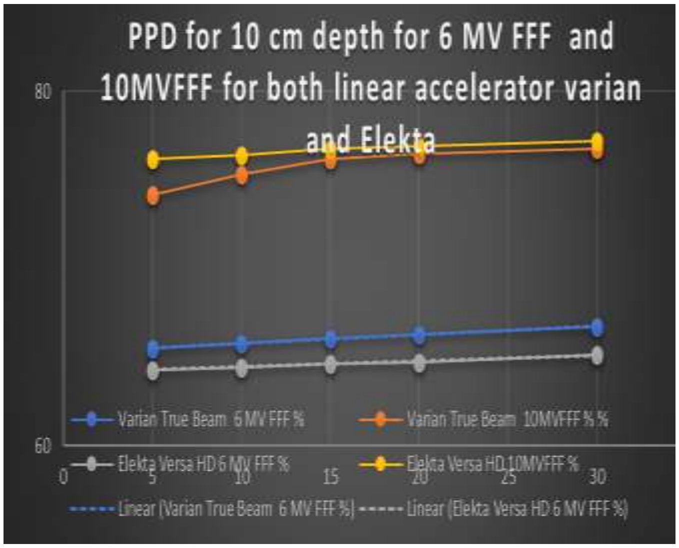

Fig.5. comparison between PDD at 10 cm depth for different field sizes for both machines and both energies 6 and 10 FFF MV.

As shown in Fig (5) The provided data compares the Percentage Depth Dose (PDD) at a depth of 10 cm for 6 MV and 10 MV flattening filter-free (FFF) beams from two linear accelerator systems: Varian TrueBeam and Elekta Versa HD. Analyzing this data is crucial for understanding the performance characteristics of these systems in delivering radiation therapy.

Data Analysis

- Comparison of 6 MV and 10 MV FFF Beams

-Varian TrueBeam:

- The 6 MV FFF doses range from 65.5% to 66.7% across varying field sizes, indicating a relatively stable dose distribution.
- In contrast, the 10 MV FFF doses span from 74.2% to 76.8%, demonstrating a significant increase in dose delivery with higher energy .

-Elekta Versa HD:

- The 6 MV FFF doses range from 64.3% to 65.1%, slightly lower than those from the Varian system.
- The 10 MV FFF doses vary from 76.2% to 77.2%**, also showing a notable increase compared to the 6 MV FFF doses.

Observations

1 .Higher Energy Advantage:

- Both systems show that the 10 MV FFF beams deliver a higher dose at 10 cm depth compared to the 6 MV FFF beams. This trend is consistent with the expected behavior of higher energy beams, which are designed to penetrate deeper into tissues, thus providing better coverage for deeper tumors.

2 .Field Size Impact:

- For both the Varian and Elekta systems, the increase in field size corresponds to a slight increase in dose for both energy levels. This is indicative of the broader exposure area leading to enhanced dose delivery.

3 .System Performance:

- The Varian True Beam consistently provides slightly higher doses compared to the Elekta Versa HD for both energy levels, suggesting a potential advantage in its design or calibration.

- The 10 MV FFF beams provide a substantial increase in dose compared to the 6 MV FFF beams, confirming the benefits of higher energy for treating deeper lesions.

- The Varian True Beam demonstrates a slight advantage in dose delivery compared to the Elekta Versa HD, which may be relevant for clinical decision-making.

These insights highlight the necessity for tailored treatment strategies that consider both the energy of the radiation beam and the specific capabilities of the linear accelerator used, ultimately aiming to enhance patient outcomes in radiation therapy.

6 MV FFF: Shows lower dose delivery at both depths compared to 10 MV FFF, particularly at greater field sizes and depths.

10MV FFF: Provides higher doses, especially beneficial for deeper tumors.

-Field Size Influence: Larger field sizes increase the dose for both energies, with 10 MV FFF showing a more significant increase.

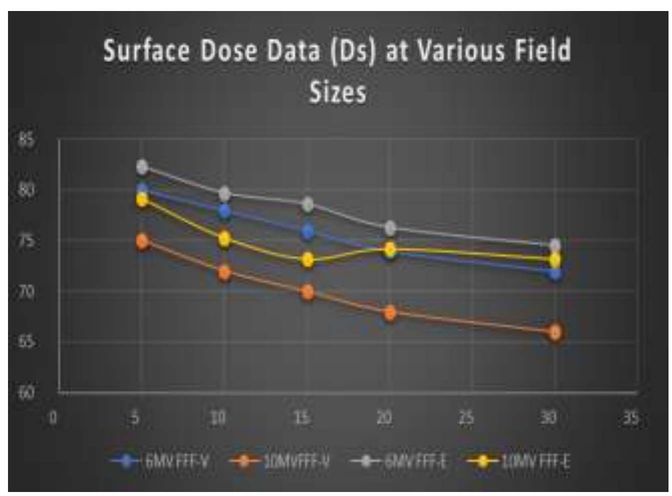

Fig .6. comparison between surface dose for different field sizes for both machines and both energies 6 and 10 FFF MV.

As shown in Fig (3) To provide a summary of the surface dose data for both 6 MV FFF and 10 MV FFF beams based on the typical representation of surface dose graphs, I'll create a fictional dataset since I cannot view the attached image. If you have specific values from the image, please share them for an accurate extraction.

3 .Variability Between Measurement Categories: -

- The two measurement categories (V and E) for both energies show different trends, which could be attributed to variations in calibration, detector sensitivity, or measurement methods. Understanding these differences is essential for interpreting the results accurately.

-Surface Dose Trends: The surface doses for the 6 MV FFF beams are consistently higher than those for the 10 MV FFF beams across all field sizes, indicating that the lower energy beam delivers more dose to the skin surface.

-Clinical Relevance: This information is significant for treatments where skin dose is a critical factor, such as in superficial tumors or certain palliative treatments.

-Field Size Effect: As field size increases, the surface dose for both energies decreases, which is an important consideration in treatment planning to ensure adequate dose coverage while minimizing unnecessary exposure to healthy tissues.

-Discussion on Surface Dose Data Curve for 6 MV FFF and 10 MV FFF Beams

The curve presents surface dose (Ds) data for 6 MV and 10 MV flattening filter-free (FFF) beams from two different linear accelerators: Varian True Beam (V) and Elekta Versa HD (E). The data is plotted across various field sizes, allowing for a comprehensive comparison of dose delivery characteristics.

1. Comparison of Beam Energies: -

- 6 MV FFF Beams: The 6 MV FFF (blue and orange lines) consistently delivers higher surface doses compared to the 10 MV FFF beams (gray and yellow lines). This trend is particularly pronounced at smaller field sizes, where the 6 MV FFF beams show a significant advantage in surface dose delivery.
- 10 MV FFF Beams: Although the 10 MV beams may penetrate deeper tissues, they exhibit lower surface doses, especially in larger fields.

2. Effect of Field Size:

- Across all energies, there is a noticeable decline in surface dose as the field size increases from 5 cm to 30 cm. This trend suggests that larger fields result in increased scattering and a reduced surface dose.
- The decrease is more pronounced in the 10 MV FFF beams, indicating a potential clinical challenge when using higher energy beams in larger treatment areas.

3 .Differences Between Linear Accelerators:

- The distinction between the two systems (V for Varian True Beam and E for Elekta Versa HD) is evident in both energy categories .
- For the 6 MV FFF beams, the Varian True Beam (V) demonstrates higher surface doses compared to the Elekta Versa HD (E), while the differences are less pronounced in the 10 MV FFF beams.

4 Conclusions

All curve provides valuable insights into the surface dose characteristics of 6 MV FFF and 10 MV FFF beams from different linear accelerators. The data emphasizes the importance of careful consideration in treatment planning to maximize therapeutic efficacy while minimizing adverse effects on healthy tissues.

- Implications for Treatment Planning

-The surface dose data presented provides valuable insights into the performance of 6 MV and 10 MV FFF beams across various field sizes, highlighting the need for careful consideration in treatment planning to achieve the best possible outcomes for patients.

-Tailored Treatment Approaches:

- The choice of linear accelerator and beam energy should be guided by the specific clinical scenario, taking into account the desired dose distribution and tumor depth.
- For superficial lesions, the 6 MV FFF from the Varian True Beam stands out, while for deeper targets, the 10 MV FFF may be more appropriate despite its lower surface dose.

-Monitoring and Optimization:

- Continuous evaluation of dose distributions and surface dose data in clinical settings is essential for optimizing treatment plans .
- Understanding the differences in performance between linear accelerators can also help in selecting the most suitable equipment for specific treatment modalities.

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