

EVALUATION OF VARIAN IX CLINICAL LINEAR
ACCELERATOR PERFORMANCE BASED ON
DAILY QUALITY ASSURANCE USING
QUICKCHECK PHANTOM

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by

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Dissertation submitted in partial fulfilment
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Bachelor of Medical Radiation (Honours)

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CERTIFICATE

This is to certify that the dissertation entitled “Evaluation of Varian iX Clinical Linear Accelerator Performance based on Daily Quality Assurance using QUICKCHECK Phantom” is the bona fide record of research work done by Ms. Nurul Afifah binti Yusniman during the period from October 2024 to August 2025 under my supervision. I have read this dissertation and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment for the degree of Bachelor in Medical Radiation (Honours)

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DECLARATION

I hereby declare that this dissertation is the result of my own investigation, except where otherwise stated and duly acknowledged. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research and promotional purpose.

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Date:

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LIST OF SYMBOLS

MV	Megavolt
MeV	Mega-electron Volt
MU	Monitor Unit
ρ	Spearman's rho
H_0	Null hypothesis
K_{norm}	Normalisation factor

LIST OF ABBREVIATION

HPUSM	Hospital Pakar Universiti Sains Malaysia
CAX Dose	Central Axis Dose
GT	Gun-target
LR	Left-right
BQF	Beam Quality Factor
QA	Quality Assurance
LINAC	Linear Accelerator
TCP	Tumour Control Probability
NTCP	Normal Tissue Complication Probability
AAPM	American Association of Physicists in Medicine
TG-142	Task Group 142
QC	Quality Control
TPR	Tissue Phantom Ratio
IMRT	Intensity-Modulated Radiation Therapy
SBRT	Stereotactic Body Radiotherapy

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LIST OF EQUATION

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Equation 6	Index for radiation quality BQF

**PENILAIAN PRESTASI LINEAR ACCELERATOR KLINIKAL VARIAN IX
BERDASARKAN JAMINAN KUALITI HARIAN MENGGUNAKAN
FANTOM QUICKCHECK**

ABSTRAK

Kajian ini bertujuan untuk menilai konsistensi prestasi linear accelerator (LINAC) Varian Clinac iX dengan menganalisis parameter output radiasi menggunakan Phantom PTW QUICKCHECK semasa prosedur jaminan kualiti (QA) harian di Hospital Pakar Universiti Sains Malaysia (HPUSM). Parameter yang diukur merangkumi dos paksi tengah (CAX), kerataan pancaran (flatness), simetri dalam arah gantri-ke-sasaran (GT) dan kiri-ke-kanan (LR), serta faktor kualiti pancaran (BQF) bagi sinar foton (6 MV) dan sinar elektron (6, 9, 12, dan 15 MeV). Data dikumpulkan sepanjang tempoh tiga bulan dari Januari hingga Mac 2025. Semua pengukuran dijalankan menggunakan saiz medan $10 \times 10 \text{ cm}^2$ dengan 100 MU dihantar pada kadar dos 300 MU/min. Pengukuran diulang sekiranya berlaku ralat bacaan, dan sebarang data tidak sah dikecualikan daripada analisis. Hasil kajian menunjukkan bahawa semua parameter output radiasi berada dalam had toleransi yang disyorkan oleh AAPM TG-142 ($\pm 3\%$), sekali gus menunjukkan kestabilan output dan prestasi mesin yang sangat baik. Ini mengesahkan kesesuaian peranti QUICKCHECK sebagai alat yang boleh dipercayai dan efisien untuk QA harian secara rutin dalam persekitaran radioterapi.

Kata kunci: Linear accelerator, Jaminan kualiti harian, Phantom QUICKCHECK, Konsistensi output pancaran, QA Radioterapi.

**EVALUATION OF VARIAN iX CLINICAL LINEAR ACCELERATOR
PERFORMANCE BASED ON DAILY QUALITY ASSURANCE
USING QUICKCHECK PHANTOM**

ABSTRACT

This study aims to evaluate the performance consistency of the Varian iX Clinical Linear Accelerator (LINAC) by analysing radiation output parameters using the PTW QUICKCHECK Phantom during daily quality assurance (QA) procedures at Hospital Pakar Universiti Sains Malaysia (HPUSM). The parameters measured include central axis dose (CAX), beam flatness, symmetry in the gantry-target (GT) and left-right (LR) directions, and beam quality factor (BQF) for photon (6 MV) and electron beams (6, 9, 12, and 15 MeV). Data were collected over a three-month period from January to March 2025. All measurements were taken using a $10 \times 10 \text{ cm}^2$ field size with 100 MU delivered at a dose rate of 300 MU/min. Repeated measurements were conducted in cases of reading errors, and any invalid data were excluded from the analysis. The results showed that all radiation output parameters remained within the tolerance limits recommended by AAPM TG-142 ($\pm 3\%$), indicating excellent output stability and machine performance. This confirms the suitability of the QUICKCHECK device as a reliable and efficient tool for routine daily QA in radiotherapy settings.

Keywords: Linear accelerator, Daily quality assurance, QUICKCHECK Phantom, Beam output consistency, Radiotherapy QA.

CHAPTER 1

INTRODUCTION

1.1 Background of study

In radiotherapy, ionising radiation interacts with cancerous cells to induce ionisation either directly via charged particles such as electrons or positrons or indirectly through high-energy photons such as x-rays and gamma rays (Gill et al., 2024). LINAC is a widely used device in clinical oncology to deliver precise and targeted radiation doses to malignant tissues. The primary objective of radiation therapy is to maximize the radiation dose to the tumour while minimising exposure to surrounding healthy tissues and organs at risk.

Photon beams are predominantly implemented in delivering high-quality radiotherapy due to their penetrative and dosimetry characteristics. To maintain the effectiveness and safety of radiotherapy, it is essential that the LINAC operates with high stability and undergoes thorough quality control. Studies on tumour control probability (TCP) and normal tissue complication probability (NTCP) have concluded that deviations greater than 7% in dose delivery can produce clinically significant effects on both tumours and surrounding normal tissues (Lamichhane et al., 2023).

In response to the need for consistent treatment accuracy, the American Association of Physicists in Medicine (AAPM) established a set of comprehensive QA guidelines under Task Group reports such as TG-142 (Hanley et al., 2021). QA is a systematic process carried out to ensure that the performance of the radiation therapy equipment remains consistent with the reference values established during calibration. In other words, QA helps verify that the output measured today matches the calibrated

output from commissioning. Within the QA framework, quality control (QC) refers specifically to the set of routine tests and procedures performed to monitor and maintain the machine's operational integrity. These protocols recommend daily, monthly, and annual QA tests to ensure that all machine parameters remain within acceptable tolerance limits. QA plays an important role in reducing uncertainties, identifying errors early, and minimising potential complications or tumour recurrence during patient treatment. Establishing a reliable setup for daily output measurements is necessary for maintaining the precision and consistency of LINAC performance.

To support daily QA processes, devices such as the PTW QUICKCHECKwebline have been introduced as efficient, wireless systems designed to monitor key beam parameters. QUICKCHECKwebline demonstrated good linearity and reproducibility, making it a suitable candidate for routine output verification (Lamichane et al., 2023). The system incorporates built-in ionisation chambers that assess CAX dose, flatness, symmetry, and BQF with minimal setup. Its cable-free design and integrated software streamline the QA process, enabling quick evaluations and data logging without the need for extensive training.



Figure 1.1: PTW QUICKCHECK Phantom placed in its docking station for charging after daily QA use

As illustrated in Figure 1.1, the QUICKCHECK Phantom is placed in its docking station for charging after daily QA procedures, highlighting its regular use in clinical workflow. This device provides a practical alternative to time-consuming preventive maintenance by enabling fast and consistent assessment of LINAC performance. Based on Table 1.1, the key radiation output parameters, such as CAX dose, flatness, symmetry, and BQF are subject to specific tolerance limits, with most parameters expected to remain within $\pm 3\%$ as recommended by AAPM TG-142. By maintaining output variations within these limits, the constancy of radiotherapy treatments can be effectively upheld. Despite its clinical utility, there remains limited published research evaluating the long-term performance of the QUICKCHECK system in ensuring LINAC output stability.

Table 1.1: Key QA Tolerances in Linac Performance (Based on TG-142)

Parameter	Tolerance	Reference
CAX Dose	$\pm 3\%$	TG-142
Beam Flatness	$\pm 2\%$	TG-142
Beam Symmetry	$\pm 2\%$	TG-142
BQF	$\pm 2\%$	TG-142

This study aims to evaluate the operational constancy of the QUICKCHECK by analysing its performance in measuring key LINAC parameters over time. By comparing CAX Dose, flatness, symmetry, and BQF against baseline values, the study intends to assess the device's suitability for supporting daily QA in alignment with internationally accepted tolerances and standards.

1.2 Problem statement

Many radiotherapy institutes still struggle to implement international QA protocols due to inadequate equipment, a lack of national guidelines, and limited resources. Conventional morning QA using traditional phantoms is often time consuming and primarily relies on Tissue Phantom Ratio (TPR_{20,10}) measurements, which may not fully capture variations in beam parameters (Nyaichyai et al., 2022).



Figure 1.2: PTW 30010 Farmer Chamber (Kweon et al., 2011)

One such conventional tool is the PTW 30010 Farmer Chamber as shown in Figure 1.2, typically used with solid water or slab phantoms to manually measure dose output. Although widely adopted, this method is generally time consuming as it involves multiple manual steps and equipment setup, which can delay the QA workflow. Compared to modern automated devices, conventional QA using this setup is less efficient and more susceptible to human-related inconsistencies

Over time, LINAC performance may degrade, requiring early detection through predictive QA systems. Without effective monitoring, unplanned machine downtime and treatment inaccuracies may occur. Even minor inconsistencies in beam parameters can introduce subtle treatment errors, highlighting the need for frequent and sensitive QA assessments (Lamichhane et al., 2023).

Existing daily QA devices often lack the precision required for accurate LINAC performance monitoring. Studies show that the QUICKCHECK Phantom offers superior accuracy compared to other QA tools, such as the Daily QA™ M3, particularly in output, flatness, symmetry, and beam quality measurements (Nicewonger et al., 2019).

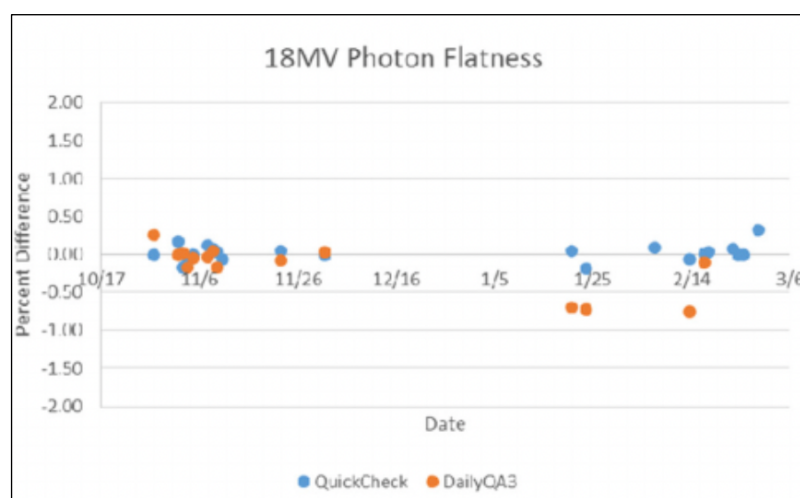


Figure 1.3: Percent difference in 18 MV photon flatness measurements using QUICKCHECK and Daily QA™ M3.

As illustrated in Figure 1.3, the percent difference for 18 MV photon flatness measurements demonstrate more consistent and centralised values for QUICKCHECK compared to the Daily QA™ M3. Adopting more reliable QA tools can enhance treatment accuracy, improve patient safety, and optimize radiotherapy outcomes. Therefore, the purpose of this study is to use the QUICKCHECK Phantom to monitor selected daily QA parameters of the LINAC, with the aim of evaluating the consistency of daily QA measurements using this device.

1.3 Aims and objectives

General Objective

The aim of this research project is to evaluate the performance constancy of the Varian iX Clinical Linear Accelerator (LINAC) by analysing radiation output parameters using the QUICKCHECK Phantom during daily QA at Hospital Pakar Universiti Sains Malaysia (HPUSM).

Specific Objectives:

1. To measure the CAX Dose, flatness, symmetry, and BQF of the Varian iX Clinical Linear Accelerator using the QUICKCHECK Phantom.
2. To analyse the radiation output parameters within tolerance limit by AAPM Task Group 142 (TG-142).
3. To evaluate the correlation between the LINAC's radiation output parameters measured using the QUICKCHECK Phantom during daily QA.

1.4 Significance of study

In order to ensure stability in radiation delivery, this study uses the QUICKCHECK Phantom to assess the constancy of LINAC radiation output parameters as part of routine daily QA. According to the null hypothesis, there is no noticeable shift in the measured parameters, and the ideal machine performance is achieved when the expected values stay within $\pm 3\%$. This study highlights the significance of keeping an accurate Varian iX Clinical Linear Accelerator system by determining output constancy, which is going to enhance radiation therapy's accuracy and safety. Findings contribute to improved patient outcomes, streamlined QA protocols, and higher treatment reliability in clinical radiotherapy settings.

CHAPTER 2

LITERATURE REVIEW

2.1 The Importance of QA Using Phantom in Radiotherapy

Radiotherapy is a fundamental component of cancer treatment, delivering high-energy ionising radiation to destroy malignant cells while sparing surrounding healthy tissue. The precision and accuracy of radiation dose delivery are vital, as even small deviations can lead to significant clinical consequences (Takahashi et al., 2025). To ensure the reliability and safety of LINAC machines used in radiotherapy, a robust QA program is essential. Within this context, the use of phantoms, specially designed devices that simulate human tissue or beam interaction is widely employed as a key component of QA procedures. This section explores the necessity of QA in radiotherapy and emphasizes the growing role of phantom-based devices in routine machine performance monitoring.

2.2 The Role of QA in Radiotherapy

QA in radiotherapy encompasses systematic checks and procedures to verify that the treatment planning and delivery processes function within defined tolerances. AAPM, through reports such as TG-40 and TG-142, provides comprehensive guidelines for conducting QA tests on medical accelerators. These protocols establish the frequency and tolerances for measurements, including daily, monthly, and annual QA checks, covering parameters such as output constancy, flatness, symmetry, and energy consistency.

The need for stringent QA arises from the direct impact of radiation dose accuracy on treatment outcomes. Studies have shown that dose deviations as small as 5–7% can result in measurable changes in TCP and NTCP. Therefore, maintaining output constancy within $\pm 3\%$ is not just a recommendation but a clinical imperative (Jiang et al., 2020). QA ensures that LINACs perform according to baseline commissioning data and helps detect performance drift or mechanical malfunctions before they can affect patient treatment.

Nyaichyai et al. (2022) underline that QA is particularly crucial in settings where there are no national guidelines for radiotherapy QA. In such contexts, institutions rely on international protocols like AAPM TG-142 and IAEA TRS-398, which may not always align perfectly with local resources or clinical practices. The study emphasizes that QA is essential for adapting global standards to local workflows, especially to ensure safe and consistent radiotherapy delivery. Nyaichyai et al. (2022) also highlight how resource constraints, such as limited trained staff or unavailability of certain dosimetry tools can make the implementation of effective QA protocols more challenging, further emphasizing the need for efficient and practical QA solutions.

2.3 Conventional QA Methods and Their Limitations

Historically, QA procedures were conducted using conventional phantoms and Farmer-type ionisation chambers (Figure 1.2). These systems provide high accuracy and are used extensively for reference dosimetry and absolute dose calibration. However, such methods can be labor-intensive and time-consuming, particularly when repeated frequently for daily checks. According to Nyaichyai et al. (2022), conventional daily QA typically involves verifying output and beam quality using basic tools, which might only

assess parameters like TPR20/10 for photon beams. These tests, although accurate, often neglect other key parameters such as symmetry, flatness, and energy constancy.

Moreover, manual QA processes depend heavily on operator expertise and may be prone to inconsistencies in execution or interpretation (Dhoundiyal et al., 2024). In busy clinical settings, the time required for setup and data analysis using traditional QA tools can lead to workflow inefficiencies. More automated and integrated QA solutions are necessary in considering this reality, especially for daily machine performance monitoring. These newer systems must maintain the reliability of conventional methods while offering greater speed, ease of use, and comprehensiveness (Nyaichyai et al., 2022).

2.4 Emergence of Modern Phantom-Based QA Tools

To address the limitations of conventional QA approaches, modern phantom-based QA devices have been developed. One such innovation is the PTW QUICKCHECKwebline, a compact, lightweight, and automated phantom designed for daily QA. This device integrates multiple vented ion chambers within a single unit, allowing it to measure output constancy, flatness, symmetry, and beam energy in a single beam exposure. Both Nyaichyai et al. (2022) and Jiang et al. (2020) conducted studies evaluating the performance and effectiveness of this device in routine clinical QA.

In their 2022 study, Nyaichyai et al. applied the PTW QUICKCHECKwebline in a clinical setting to monitor the output constancy of an Elekta Synergy LINAC delivering photon and electron beams. The authors reported that all measured parameters remained within the recommended $\pm 3\%$ tolerance limits over the monitoring period. Additionally, they conducted sensitivity tests by deliberately introducing errors in gantry, couch, and collimator positions. The QUICKCHECK Phantom successfully detected these deviations, demonstrating its capacity to serve as an effective daily QA tool that is both

sensitive and reliable. This ability to detect minor positional errors is critical in high-precision treatment techniques such as Intensity-Modulated Radiation Therapy (IMRT) or Stereotactic Body Radiotherapy (SBRT), where geometric accuracy is paramount.

Similarly, Jiang et al. (2020) evaluated the same device at Zhongnan Hospital of Wuhan University using a Varian iX LINAC. Their findings further validated the reproducibility and linearity of the QUICKCHECKwebline readings compared to the Farmer chamber. Over a six-month period, output deviations measured by the QUICKCHECK remained within 1% of the standard value. Notably, the authors highlighted that consistent use of the phantom in morning QA could predict potential machine faults, such as malfunction in the monitor chamber, before they caused significant deviations or treatment errors. This application demonstrates that phantom-based daily QA not only verifies current machine status but also acts as a predictive maintenance tool.

2.5 Clinical Significance of Phantom-Based Daily QA

The studies mentioned underscore the clinical importance of integrating phantom-based tools into daily QA routines. Both research teams emphasized that daily checks using the QUICKCHECK device improve the safety and consistency of patient treatments by catching errors early and confirming the stability of beam parameters. In particular, Jiang et al. (2020) observed that when deviations exceeded 2%, physicists were able to intervene promptly with recalibration or further investigation using ionisation chambers. This proactive approach can prevent cumulative errors that might otherwise compromise treatment accuracy.

Furthermore, phantom-based devices streamline QA procedures. Since the PTW QUICKCHECKwebline consolidates multiple checks into a single measurement, it

significantly reduces the time and manpower required for routine QA without sacrificing measurement accuracy. Nyaichyai et al. (2022) noted that the device provided not only measurement data but also integrated software with a pass/fail system and trending analysis, enhancing long-term monitoring capabilities. This combination of convenience, automation, and data tracking supports clinical decision-making and regulatory compliance.

In addition to operational benefits, the clinical value of such QA systems lies in their ability to support safe, high-precision treatment delivery. Modern radiotherapy techniques depend on consistent machine performance, and regular verification with phantom-based tools ensures that complex treatment plans are executed as intended. For institutions with high patient throughput or limited staff, automated phantoms represent an optimal solution for maintaining quality without overburdening personnel.

The consistent and accurate delivery of radiation dose in radiotherapy relies on the implementation of effective QA systems. Conventional methods, while precise, are often inefficient for daily application. The evolution of phantom-based QA tools such as the PTW QUICKCHECKwebline addresses these limitations by offering comprehensive, quick, and user-friendly alternatives. As demonstrated by Nyaichyai et al. (2022) and Jiang et al. (2020), these tools are not only capable of ensuring machine output constancy but also sensitive enough to detect geometric and dosimetry deviations, reinforcing their indispensable role in modern QA practice.

By integrating phantom-based devices into daily QA routines, radiotherapy centres can ensure safer treatment delivery, improved operational efficiency, and better compliance with international standards. These findings provide a strong foundation for the present research, which aims to evaluate output performance consistency using phantom-based QA devices in a clinical radiotherapy setting.

2.6 Parameters Measurable by Phantom-Based Quality Assurance

As mentioned earlier, QA using phantom devices plays a critical role in ensuring the accuracy and safety of radiotherapy treatments. The increasing use of phantoms such as the PTW QUICKCHECKwebline reflects a shift from conventional, manual dosimetry methods to more streamlined, automated tools capable of verifying machine performance in real time (Nyaichyai et al., 2022). Following the establishment of daily QA as essential for maintaining treatment reliability and minimising clinical errors, attention turns to the specific dosimetry parameters that phantom devices are designed to measure. A clear understanding of what these parameters represent and how accurately they are monitored is fundamental to appreciating the full value of phantom-based QA in clinical practice. Daily QA of LINAC is not only a regulatory requirement but a clinical necessity to ensure accurate dose delivery in radiation therapy. As technological advancements continue to enhance the capabilities of QA devices, phantoms such as the PTW QUICKCHECKwebline have emerged as highly reliable tools for verifying multiple beam parameters with high sensitivity and precision. This section reviews the key measurable parameters that can be assessed using phantom QA devices and explains their clinical significance based on findings from recent studies.

2.7 Introduction to Phantom-Measured Parameters

Modern QA phantoms like the PTW QUICKCHECKwebline are capable of simultaneously measuring a range of critical beam parameters in a single exposure. These include the CAX, beam flatness, beam symmetry in both gun-target (GT) and left-right (LR) directions, and the BQF. These parameters are foundational in determining the consistency and accuracy of a LINAC's performance. According to Lamichhane et al. (2023), these measurements are essential not only for photon beams but also for electron

beams across a range of energies and field sizes. The study emphasizes that any deviation from expected values, even if within tolerance, should be closely examined to prevent cumulative errors in patient treatment

2.7.1 Central Axis Dose (CAX)

The central axis dose represents the dose measured at the centre of the beam field, which serves as a reference point for all other QA measurements. In the PTW QUICKCHECKwebline system, the central ionisation chamber (CAX) directly records the output dose, which is then normalized against baseline values to assess consistency. Lamichhane et al. (2023) highlights that the CAX measurement provides immediate insight into the LINAC's output constancy and is particularly sensitive to setup errors, such as misalignment of the phantom with the scattering foil. Variations observed in the study generally stayed within the AAPM TG-142 recommended tolerance limit of $\pm 3\%$, reinforcing the reliability of daily CAX monitoring.

2.7.2 Beam Flatness

Flatness is defined as the uniformity of the radiation intensity across the field at a specified depth in tissue or water. It reflects the beam's capability to deliver an even dose across the treatment area. The QUICKCHECKwebline measures flatness using readings from central and peripheral ionisation chambers positioned symmetrically in the beam's cross-section. The study by Lamichhane et al. (2023) found that flatness readings were especially sensitive in the $10 \times 10 \text{ cm}^2$ field compared to the $20 \times 20 \text{ cm}^2$ field, particularly for photon beams. Minor variations were detected due to energy fluctuations or setup inconsistencies, but all remained within the clinically acceptable range. Importantly,

flatness serves as a key indicator for detecting beam steering errors or issues with flattening filters.

2.7.3 Beam Symmetry

Beam symmetry evaluates the mirror-like balance of dose distribution about the central axis, both in the gantry-to-target (GT) and left-to-right (LR) directions. In the QUICKCHECKweblin device, symmetry is calculated using pairs of chambers placed equidistant from the central axis. According to the findings by Lamichhane et al. (2023), the QUICKCHECKweblin effectively detected minor asymmetries, with one outlier attributed to phantom mispositioning rather than LINAC malfunction. Most data fell within AAPM-recommended tolerances, confirming the device's sensitivity in detecting setup and beam delivery errors. Symmetry checks are particularly valuable in high-precision modalities like IMRT, where even slight beam asymmetries could impact dose conformity.

2.7.4 Beam Quality Factor (BQF)

The beam quality factor (BQF) provides information about the penetrating power and energy characteristics of the beam. It is determined by the ratio of readings from peripheral ionisation chambers to the central chamber and is especially important for identifying energy drifts. The study showed that BQF measurements for both photon and electron beams were stable across multiple sessions, with some minor variations early in the data collection period. Lamichhane et al. (2023) suggest that these early deviations could be linked to incomplete normalization or initial setup variations. Nevertheless, the long-term data indicated that the BQF remained a consistent and reliable indicator of beam quality across all measured energies.

2.8 Electron Beam Monitoring

While much QA literature emphasizes photon beam assessment, Lamichhane et al. (2023) also provides valuable insights into QA measurements for electron beams using QUICKCHECKwebline. Electron energy outputs (6, 9, 12, and 15 MeV) were evaluated for both 10×10 cm² and 20×20 cm² fields. The CAX, flatness, symmetry, and BQF of electron beams were measured across five ionisation chambers, with results plotted for trend analysis. The findings indicate that electron beam outputs showed slightly greater variation in symmetry readings, attributed to secondary collimator performance and applicator positioning but remained largely within tolerance limits. This highlights the utility of phantom QA in electron beam verification, a component sometimes underemphasized in daily practice.

2.9 Reproducibility and Linearity of Measurements

A key strength of the QUICKCHECKwebline device lies in its reproducibility and linearity. Lamichhane et al. (2023) conducted a short-term reproducibility test using monitor unit (MU) increments between 70 and 130 MU. The device demonstrated a linear response consistent with LINAC output, confirming its capability to detect small fluctuations in output with precision. This supports previous findings by Jiang et al. (2020), who also validated the linearity of the QUICKCHECKwebline over six months of daily use. Consistent reproducibility ensures that the phantom can be trusted for detecting both subtle drifts and sudden faults in beam delivery.

2.10 Parameters and Clinical Relevance

The study by Lamichhane et al. (2023) provides comprehensive evidence that the PTW QUICKCHECKwebline can effectively and accurately measure key QA parameters including CAX, flatness, symmetry (GT and LR), and BQF for both photon and electron beams. The consistent readings across multiple sessions confirm the reliability of the device for routine QA tasks. More importantly, the ability to monitor multiple parameters simultaneously makes the phantom highly efficient for daily clinical use, reducing the risk of undetected machine performance drifts.

All measured values in the study fell within the $\pm 3\%$ tolerance recommended by AAPM TG-142, affirming that the phantom is suitable for verifying LINAC performance and supporting safe radiotherapy delivery. The study also reinforces the importance of understanding how each parameter responds to machine, environmental, or procedural changes. When deviations are observed, physicists can use this information to take corrective action such as recalibrating the beam or adjusting the treatment setup before patient treatment begins.

2.11 Compliance of Phantom-Measured Parameters with International Quality Assurance Standards

The accuracy and consistency of LINAC performance must be assessed not only through the capability of QA tools to measure dosimetry parameters, but also by evaluating whether the measured values comply with recognized international standards. The American Association of Physicists in Medicine (AAPM) Task Group 142 (TG-142) report provides widely adopted tolerance levels for key parameters such as output constancy, beam flatness, symmetry, and energy constancy. The PTW

QUICKCHECKwebline Phantom, widely used in daily QA protocols, has been the subject of various studies assessing its ability to generate clinically acceptable measurements within these standard tolerances. This section reviews the performance of the QUICKCHECK Phantom based on empirical data and evaluates its compliance with the TG-142 tolerance criteria.

According to TG-142, the acceptable tolerance limits for daily QA are defined as $\pm 3\%$ for output constancy, $\pm 2\%$ for beam flatness, $\pm 2\%$ for beam symmetry in both the in-plane and cross-plane directions, and $\pm 2\%$ for energy constancy, often evaluated using a beam quality factor (BQF). These thresholds are designed to ensure that beam delivery remains within safe clinical margins, thereby minimising the risk of underdosage or overdosage to the patient.

Nicewonger et al. (2019) conducted a comparative study between the QUICKCHECKwebline and the widely used Daily QATM3 Phantom over a four-month period. Their findings revealed that all parameters measured by the QUICKCHECK device, including output, flatness, symmetry, and energy, remained well within the TG-142 recommended limits. Specifically, output deviations across all energies did not exceed $\pm 1.5\%$ from the baseline, while beam flatness remained within $\pm 1.36\%$. Symmetry in both in-plane and cross-plane directions was observed to be within $\pm 1.41\%$, and BQF measurements exhibited variations no greater than $\pm 0.91\%$. These findings support the reliability and clinical suitability of the QUICKCHECK Phantom for routine daily use.

A similar conclusion was reached by Lamichhane et al. (2023), who evaluated the QUICKCHECKwebline across a range of photon and electron beam energies. Their study confirmed that measurements for CAX, flatness, symmetry, and BQF were consistently within the acceptable range throughout the observation period. The highest deviations

reported still remained below the TG-142 thresholds, reinforcing the device's capacity to maintain beam constancy within clinically acceptable limits.

However, more variable results were reported by Naz et al. (2023), who evaluated the QUICKCHECK device over a 50-day period for daily quality checks involving both photon and electron beams. While measurements of beam symmetry and output constancy consistently fell within the specified tolerance limits of $\pm 2\%$ and $\pm 3\%$, respectively, some deviations were observed in flatness measurements. For instance, only 7.3% of 6 MV photon beam data and 7.31% of 15 MV photon beam data fell within the $\pm 3\%$ flatness tolerance. For electron beams, flatness compliance ranged from 16.12% at 6 MeV to 4.01% at 15 and 18 MeV. These results indicate that flatness is more susceptible to variation, possibly due to daily setup inconsistencies or machine-specific factors, and suggest a need for careful phantom positioning and consistent environmental conditions during QA procedures.

Despite the occasional deviations in flatness observed by Naz et al., (2024), the consistency in other key parameters, particularly symmetry and CAX, highlights the device's reliability in capturing stable beam characteristics. The reproducibility and repeatability of symmetry values across multiple sessions and energy levels further validate the utility of the QUICKCHECK device for detecting potential performance drifts in LINAC systems

Energy constancy, as assessed by BQF, also demonstrated robust stability across the studies reviewed. In the study by Nicewonger et al. (2019), BQF values measured with the QUICKCHECK device remained within $\pm 1.29\%$ for all photon and electron energies. This finding aligns with the TG-142 tolerance of $\pm 3\%$ and indicates the capability of the phantom to effectively monitor potential changes in beam penetration and energy characteristics. Similarly, Lamichhane et al. (2023) reported stable BQF

readings throughout their monitoring period, supporting the device's use in detecting energy-related inconsistencies.

These results suggest that the PTW QUICKCHECKwebline consistently meets international quality standards in most QA categories. Deviations in flatness, while noted in specific cases, appear to be the exception rather than the norm and are likely influenced by factors external to device performance, such as operator handling or beam setup accuracy. Moreover, the device's software capabilities, including automated pass/fail indicators and trending tools, enhance its clinical practicality by enabling quick assessment and documentation.

In conclusion, the parameters measured by the QUICKCHECK Phantom particularly CAX, symmetry, flatness, and BQF demonstrate strong compliance with TG-142 recommendations across multiple studies. This underscores the phantom's effectiveness in ensuring reliable daily LINAC performance and supports its continued integration into modern QA workflows. These findings provide further evidence of the device's role in maintaining the quality and safety of radiotherapy treatment delivery.

CHAPTER 3

MATERIAL AND METHOD

QA involves organised procedures and measures designed to uphold a high standard in patient diagnosis or treatment. As medical technology becomes more complex, it demands specialized and systematic checks to ensure safety, effectiveness, and prevent errors (Amurao et al., 2023). QA in clinical radiotherapy is a standard and required process meant to guarantee that machines provide patients with accurate and consistent radiation doses. Radiotherapeutic and metabolic treatments must be delivered with high precision and accuracy to ensure their effectiveness. Various factors can influence the success of radiation therapy. Implementing structured QA protocols helps reduce potential side effects for patients and enhances the efficiency of treatment delivery (Kron et al., 2022). Thus, under guidelines of current professional standards and institutional protocols, QA programs for LINACs are made to monitor and validate important performance criteria daily. QA procedures are important for verifying the accuracy of the delivered dose and the spatial precision of the radiation beam, ensuring that the treatment effectively targets the tumour while minimising exposure to surrounding healthy tissues (Dhoundiyal et al., 2024)

This project uses a combination of hardware and software tools to collect, analyse, and verify QA data. The PTW QUICKCHECKwebline is a lightweight, portable dosimetry device designed for daily QA, capable of evaluating flatness, symmetry, beam quality, and output consistency in a single radiation exposure. (Nyaichyai et al., 2022). The phantom works with the QUICKCHECK software platform, enabling real-time feedback and analysis of historical trends. The QA process follows the best practices

outlined in recent studies, expanding on the original AAPM Task Group 142 (TG-142) recommendations.

3.1 Materials

3.1.1 Varian iX Clinical Linear Accelerator

The Varian iX is a medical linear accelerator widely used in EBRT for treating various cancers with high precision. Installed at HPUSM since 2016, it supports advanced techniques such as conformal therapy, IMRT, and VMAT. The system integrates hardware and software to control gantry rotation, collimator and jaw positions, multileaf collimators (MLC), and radiation output, ensuring precise and safe dose delivery (Subaar et al., 2024).

At HPUSM, the LINAC is configured to deliver photon beams up to 6 MV and electron beams up to 15 MeV. Treatment plans are created using the Eclipse™ Treatment Planning System and transferred to the LINAC via the DICOM-RT protocol. The ARIA® Oncology Information System (OIS) is used to manage patient data, scheduling, and treatment parameters.

Daily QA procedures are conducted using fixed dose rates for consistency. While the system allows dose rates of 300–600 MU/min, HPUSM standardizes QA delivery at 200 MU/min for general QA and 180 MU/min for photon output constancy. The LINAC also features isocentric accuracy within ± 1 mm, critical for maintaining geometric and dosimetric precision (Krauss et al., 2023). This consistent setup and operational protocol support the reliable performance of the Clinac iX in both clinical treatment and daily QA, forming the foundation for evaluating its radiation output in this study.

3.1.2 Quality Assurance tools

In radiation therapy, QA plays a crucial role in ensuring both the safety and effectiveness of treatment delivery. LINACs are high-precision machines, and their performance can degrade over time due to component wear, mechanical shifts, or environmental influences. Therefore, routine QA is essential to ensure that the machine delivers radiation accurately and within the prescribed limits, maintaining consistent beam output throughout the course of treatment. It also helps in the early detection of equipment malfunctions, allowing timely maintenance and reducing the risk of treatment errors.

3.1.2.1 QUICKCHECK Phantom

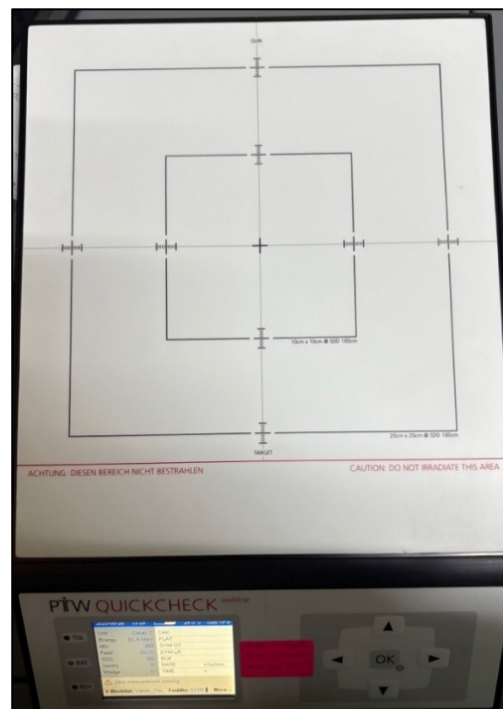


Figure 3.1: QUICKCHECK Phantom (PTW-Freiburg) used for daily QA of the Varian iX Clinical Linear Accelerator

To perform daily QA efficiently, many clinics utilize automated devices like the QUICKCHECK Phantom. Manufactured by PTW-Freiburg, this device enables quick, accurate, and consistent assessment of LINAC beam characteristics with just a single exposure. Among its key features are pre-calibrated ion chamber arrays for evaluating dose, symmetry, and flatness. A compact and portable design that simplifies daily use and integrated software solutions (such as QUICKCHECK Webline or Detector Interface) that facilitate automated data acquisition, analysis, and long-term trend monitoring. The device is compatible with various LINAC models, including the Varian iX Clinical Linear Accelerator. At HPUSM, the QUICKCHECK Phantom has been used as part of daily QA protocol since August 2024. During use, the phantom is placed at the isocentre on the treatment couch and aligned with the central axis using room lasers or alignment guides. A short beam delivery session provides the data, which is automatically compared against baseline values and tolerance thresholds.

The PTW QUICKCHECK Phantom is used daily to assess the core beam parameters of a LINAC, ensuring the machine's readiness for safe and accurate radiation therapy. As shown in Figure 3.1, the surface of the QUICKCHECK Phantom displays the square outline and visible chamber positions, which represent the internal layout of the ionisation chambers embedded within the device. The QUICKCHECK is equipped with 13 vented ionisation chamber detectors that are air density compensated, ensuring accurate and reliable measurements under varying environmental conditions. The device features compact outer dimensions of 380 mm × 254 mm × 67 mm. The system supports a range of constancy tests, including CAX dose, radiation quality, beam symmetry, flatness, and both fixed and dynamic wedge angle verification.

The PTW QUICKCHECK Phantom is a commercially available device used for rapid and reliable daily QA of LINAC. It is engineered to be compact, user-friendly, and