CHAPTER 1 INTRODUCTION

1.1 Background

Cancer is the second leading cause of death worldwide in the category of non-communicable diseases (World Health Organization (WHO), 2024). Based on data released by WHO through the International Agency for Research on Cancer (IARC), estimates of cancer cases in Indonesia in 2022 show that there were 408,661 new cases of cancer and 242,988 deaths, dominated by cancer of the breast, lung, cervix uteri, colorectum, and liver (IARC, 2024). Cancer is a miscommunication between cells, accompanied by massive growth of cells and tissues in localized parts of the body (Tarin, 2023). An effective treatment method is needed to control the growth or damage of cancer cells. One of the most widely used treatment methods is radiotherapy, which around 50% of patients require at some point during their treatment journey (Midgley, 2023). Radiotherapy damages cancer cells by utilizing ionizing radiation. Based on the location of the radiation source, radiotherapy is divided into two categories: brachytherapy, where the radiation source is placed inside the patient's body, and teletherapy/External Beam Radiotherapy (EBRT), where the radiation source is positioned outside the patient's body.

A linear accelerator (LINAC) is one of the EBRT modalities. LINAC accelerates charged particles, such as electrons, with high-frequency electromagnetic waves to produce X-rays (photons) or electron beams that are applied in cancer treatment, depending on the depth of the cancer. The existence of LINAC as a teletherapy device is still limited in West Sumatra (Sumbar). Until 2023, only one LINAC was available in Sumbar, namely the Varian Clinac CX LINAC at Andalas University Hospital. Based on the 2023 Indonesian Health Survey (SKI) released by the Ministry of Health of the Republic of Indonesia (Kemenkes RI), Sumbar is in the top three provinces with the highest cancer prevalence in Indonesia (Badan Kebijakan Pembangunan Kesehatan, 2023). In

2024, the number of LINACs in West Sumatra increased with the procurement of one VitalBeam LINAC in Bukittinggi City, specifically at the Dr. Achmad Mochtar Regional General Hospital (RSAM) Bukittinggi.

As a clinical modality, LINAC is required to deliver accurate radiation doses according to the patient's treatment plan. Recommendations from the International Commission on Radiation Units and Measurements (ICRU), adopted in the American Association of Physicists in Medicine (AAPM) Task Group 40 (TG-40) and updated in TG-142, stipulate that the deviation in the dose received by the patient must not exceed ± 5% of the prescribed dose (Klein et al., 2009). To ensure this level of accuracy, a comprehensive and ongoing Quality Assurance (QA) program is necessary to maintain LINAC performance, ensuring it does not deviate from the baseline values established during commissioning (Efendi et al., 2020).

In practice, QA evaluation of beam performance in healthcare facilities often faces challenges, including the lack of uniform standards and high precision requirements. This condition can lead to minimal QA practices, focusing on the verification of basic parameters such as flatness and symmetry, and their comparison with commissioning reference data (Efendi et al., 2020). This approach is considered insufficiently comprehensive because these two parameters represent only average values and are not sensitive to local variations in the beam profile. For photon beam commissioning, the AAPM TG-106 Report recommends a minimum number of data points, namely Percent Depth Dose (PDD) and dose profile in-plane and/or cross-plane, or beam profile at various depths (Das et al., 2008). PDD is used as a beam quality parameter so that the dose works optimally at the planned area and depth, while the beam profile is used to assess the reliability of lateral radiation doses (Efendi et al., 2020).

To conduct a comprehensive evaluation of all points on the PDD curve and beam profile, a Monte Carlo simulation can be an ideal verification modality. This numerical method is based on random number sampling to simulate stochastic processes (Rizani et al., 2012), is recognized as the gold standard for reliable absorbed dose calculations because it provides the most detailed and complete

description of the radiation field and particle transport in tissue (Esposito et al., 2018). Monte Carlo simulations can help analyze discrepancies between measured and calculated doses, as well as identify whether the cause stems from machine performance failure or Treatment Planning System (TPS) calculation errors. Furthermore, robust Monte Carlo codes are capable of accurately calculating doses under critical conditions where TPS is known to have accuracy limitations (Esposito et al., 2018).

General Monte Carlo codes such as FLUKA, MCNP, EGSnrc, PENELOPE, and GEANT have been utilized in medical research (Li et al., 2022), but require detailed LINAC geometry and long simulation time. PRIMO, a specialized code, offers faster simulation and supports Varian and Elekta LINAC geometries, allowing users to input a Phase Space File (PSF) or use a similar model if the specific LINAC is unavailable (Efendi et al., 2020). Unlike studies using general codes that require modeling from scratch (Bajwa et al., 2020; Chiuyo et al., 2022), PRIMO simplifies this process. Belosi et al. (2014) used the official Varian TrueBeam PSF for the TrueBeam models, achieving Gamma Passing Rate (GPR) > 99% (2%/2mm) across 10 units (Belosi et al., 2014). When the official PSF is unavailable, such as for VitalBeam, Li et al. (2022) successfully used the Clinac 2100 with tuned parameters, achieving 99% GPR (1%/1mm) but requiring 10^9 histories per parameter. Conversely, Marzon et al. (2024) and Convicto et al. (2021) validated Elekta LINAC using a more efficient approach with 10^7 histories for tuning and 10^8 histories for verification (Chiuyo et al., 2022; Marzon et al., 2024).

Using the exact parameters from Li et al. (2022) may not yield optimal agreement due to unit-to-unit variations in beam data. Belosi et al. (2014) demonstrated this issue, even using the official Varian PSF, across 10 TrueBeam units, the average GPR (1%/1mm) for lateral profile was only 86.6 % with a high standard deviation of 22.5%. Similarly, Akino et al. (2019) reported inter-unit PDD variations exceeding 1% and penumbra width variations up to 0.97 mm among TrueBeam LINACs, supporting the need for independent verification (Akino et al.,

2019). This study implements and independently verifies Li et al.'s method for the 6 MV VitalBeam at RSAM Bukittinggi by applying the same simulation setup (Clinac 2100 with their validated parameters) in PRIMO, initially comparing results against commissioning data using the stringent 1%/1mm gamma criterion. If this initial validation achieves > 90% GPR, the model will be further characterized against both commissioning and latest QA data using 1%/1mm, 2%/2mm, and 3%/3mm criteria. However, if the parameters fail to meet the > 90% GPR threshold, fine-tuning will follow Marzon et al.'s (2024) protocol, necessitated by limited computational resources and frequent power outages at our laboratory. This provides external validation of the published method in a new setting. RSAM was selected for its advanced VitalBeam technology, and the 6 MV focus is clinically justified for deep-seated tumors, which are significant contributors to cancer mortality in Indonesia, and also aligns with the study's time constraints.

1.2 Research Purposes

This research aims to:

1. Model the 6 MV VitalBeam photon beam using Li et al.'s (2022) configuration in PRIMO and validate it against the initial commissioning data using the 1%/1mm gamma criterion. If the gamma passing rate (GPR) for both PDD and beam profiles exceeds 90%, then characterize the dose distribution of this model against both the commissioning and the latest QA data using three gamma criteria: 1%/1mm, 2%/2mm, and 3%/3mm.
2. Perform independent tuning of the primary beam parameters (IEBE, FWHM-E, FWHM-FS) if the direct application of Li et al.'s parameters fails to achieve > 90% GPR under the 1%/1mm criterion. Subsequently, characterize the dose distribution of the tuned model against both the commissioning and the latest QA data using the same three gamma criteria (1%/1mm, 2%/2mm, and 3%/3mm).

1.3 Benefits of Research

This research offers practical benefits for multiple stakeholders in radiotherapy. For hospitals, it provides an efficient, simulation-based QA method for VitalBeam LINACs that, once initially validated and tuned for a specific unit, can serve as a practical supplement to routine quality assurance, saving time and resources compared to repeated full-scale measurements. For medical physicists, this simulation serves as an accurate independent verification tool for detailed beam and machine performance analysis, where the application of strict gamma index criteria (1%/1 mm) increases the sensitivity of the analysis, enabling early detection of subtle deviations that may be missed in routine inspections. For patients, it contributes to enhanced treatment safety through more thorough verification of radiation dose delivery. Furthermore, by validating the established methodology in a new clinical setting, this research strengthens the evidence base for its reliable adoption across different institutions.

1.4 Scope of Research

This research is limited to the following:

1. Using a Varian VitalBeam LINAC with 6 MV photon energy in the radiotherapy installation of RSAM Bukittinggi.
2. Using secondary data in the form of PDD data and beam profile data in ASCII format, which includes initial commissioning data and the latest QA data from the Varian VitalBeam LINAC at RSAM Bukittinggi.
3. The acquisition, analysis, and processing of all evaluation data for this research will be performed utilizing the Monte Carlo simulation-based PRIMO software.