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A Comparison of Planned Dose in TBI VMAT Treatment with Dosimetry Using Portal Dosimetry® and IBA MatriXX®

J. Sousa[1,2*], I. Lima[1], D. Olbi[2], L. Nascimento[3], A. Fidelis[4], M. Maciel[3], L. da Rosa[4] and S. C. Cardoso[3]

[1] Programa de Pós-graduação em Engenharia Nuclear, COPPE, UFRJ, Rio de Janeiro Brasil.
[2] Grupo Oncoclínicas, Rio de Janeiro, Brasil.
[3] Instituto de Física, Universidade Federal do Rio de Janeiro (UFRJ), Rio de Janeiro, Brasil.
[4] Programa de Pós-graduação em Radioproteção e Dosimetria (IRD/CNEN), Rio de Janeiro, Brasil.

*Correspondence: juan.valani@gmail.com

Abstract: Bone Marrow Transplant (BMT) is an essential therapeutic intervention in the treatment of diseases such as leukemia and lymphoma, where Total Body Irradiation (TBI) plays a crucial role by eradicating residual diseases and inducing immunosuppression, thus facilitating cell transplantation and reducing the risk of graft rejection. Traditionally, TBI has used large radiation fields, which can lead to significant toxicities in organs at risk (OARs) due to challenges in dose optimization. Volumetric Modulated Arc Therapy (VMAT) emerges as a promising technique, offering advantages such as the use of smaller treatment spaces and reduced doses to OARs, which may improve patient quality of life and reduce treatment costs. This study evaluates the effectiveness of VMAT in TBI by comparing the planned dose with the dose measured by quality control systems, such as the MatriXX FFF from IBA and the Portal Dosimetry from the VitalBeam linear accelerator, demonstrating that VMAT is a viable and effective alternative with the potential to optimize therapeutic outcomes in BMT.

Keywords: BMT, TBI, VMAT, Portal Dosimetry and IBA MatriXX.

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Uma Comparação da dose planejada no tratamento de TBI VMAT com a dosimetria usando Portal Dosimetry® e IBA MatriXX®

Resumo: O Transplante de Medula Óssea (TMO) é uma intervenção terapêutica essencial no tratamento de doenças como leucemias e linfomas, onde a Irradiação Corporal Total (TBI) desempenha um papel crucial ao erradicar doenças residuais e induzir imunossupressão, facilitando o transplante de células e reduzindo o risco de rejeição. Tradicionalmente, a TBI utiliza campos de radiação amplos, o que pode resultar em toxicidades significativas nos órgãos de risco (OARs) devido à dificuldade de otimização da dose. A Radioterapia Volumétrica de Arco Modulado (VMAT) surge como uma técnica promissora, oferecendo vantagens como o uso de espaços menores e a redução da dose nos OARs, o que pode melhorar a qualidade de vida dos pacientes e reduzir os custos de tratamento. Este estudo tem como objetivo avaliar a eficácia da VMAT na TBI, comparando a dose planejada com a dose medida por sistemas de controle de qualidade, como o MatriXX FFF da IBA e o Portal Dosimetry do acelerador linear VitalBeam, demonstrando que a VMAT é uma alternativa viável e eficaz, com potencial para otimizar os resultados terapêuticos em TMO.

Palavras-chave: TMO, TBI, VMAT, Portal Dosimetry e IBA MatriXX.

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1. INTRODUCTION

Bone Marrow Transplant (BMT) is a therapeutic modality used to treat a variety of diseases, including leukemia and lymphomas [1]. Since the pioneering work of E. Donnal Thomas and his team in March 1969, radiotherapy has been employed as a conditioning regimen in the form of Total Body Irradiation (TBI) [2]. This approach aims to irradiate the entire body to eliminate residual diseases and/or induce immunosuppression, thereby facilitating cell transplantation and reducing the likelihood of graft rejection [1].

Traditionally, Total Body Irradiation (TBI) has been administered using large, open radiation fields that irradiate the patient from distances often exceeding 2 meters from the isocenter. TBI should ideally be conducted only in large centers that handle a high volume of patients (preferably more than 20 per year) and have adequate facilities, including qualified personnel and technical support. This ensures that the procedure is performed with the necessary expertise and resources [3,4]. This non-isocentric irradiation presents several challenges, including the need for larger treatment rooms, which increases construction costs and limits the widespread adoption of the technique, as well as difficulties in optimizing the dose to radiation-sensitive organs.

Due to these optimization challenges, traditional TBI methods often result in significant toxicities in organs at risk (OARs). The most notable toxicity is interstitial pneumonitis, with occurrence rates reaching up to 60% and a mortality rate of up to 50% [5]. Additionally, nephrotoxicity, which has been linked to long-term fatalities, and cataracts, which, while not life-threatening, negatively impact post-transplant quality of life, are also concerns [6].

To address these issues, researchers have explored techniques that improve treatment performance, including Volumetric Modulated Arc Therapy (VMAT). The application of VMAT in TBI treatments, as demonstrated by various studies [1,2,7,8,9], offers several

significant advantages. These include the use of smaller treatment rooms and the ability to reduce the dose to organs at risk. Compared to conventional TBI, these advantages can decrease implementation costs, enhance the patient's quality of life, provide simultaneous boost and further critical organ sparing, improve malignant cell eradication, facilitate immune suppression and reduce toxicities [8].

Nevertheless, unresolved questions remain about this emerging treatment methodology. One specific issue is the correlation between the delivered dose and the dose measured by patient-specific quality control systems. Most studies rely on a single type of device, typically a planar detector, to verify the planned dose delivery. Therefore, the objective of this work is to plan the dose delivery using an anthropomorphic phantom from CIRS (Adult Female model) and compare the planned dose with those evaluated using two planar measurement systems.

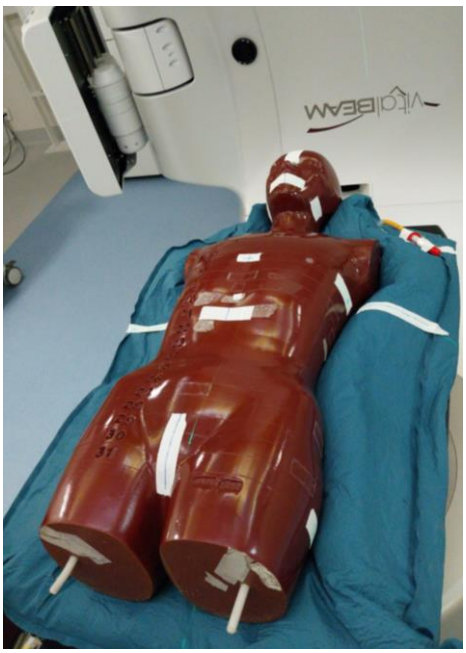
2. MATERIALS AND METHODS

2.1 TREATMENT VOLUME - PHANTOM ATOM®

The ATOM® Adult Female Model phantom from Sun Nuclear is an anthropomorphic device that simulates an adult female patient (Figure 1). It is made with three types of tissue-equivalent materials, representing lung, bone, and soft tissue. This allows for a more accurate assessment of dose distribution in a patient.

The ATOM® phantom does not have defined organs such as lenses, kidneys, and liver. One of the most important considerations for TBI treatment is the dose to the OARs as a way of inferring toxicities. To analyze the dose distribution in the region of these structures, an experienced dosimetrist used anatomical characteristics to outline an estimate of the regions corresponding to these structures.

Figure 1: ATOM® Adult Female Model positioned in the Vitalbeam® linear accelerator.



Source: The Author (2024).

2.2 TBI VMAT PLANNING

The objective of radiotherapy planning is to structure the irradiation geometry that will be performed by the linear accelerator during treatment to irradiate the planning treatment volume (PTV) with the prescribed clinical dose. Following what has already been described in the literature, the treatment volume to be considered is the body subtracting the OAR's and a margin of 0.5 cm from the skin related to the build up. The OARs considered for toxicity were those with a history of toxicity in previous treatments. In this context, the OARs are the lungs, lenses, liver, and kidneys.

The treatments were planned for the Vitalbeam® linear accelerator that has MLC Milenium 120, with a maximum field of 40x40 cm² at the isocenter position. This field size is commonly found in modern linear accelerators. Due to the size of the body in relation to the largest irradiation field, multiple treatment isocenters are used for the treatment of VMAT TBI. Therefore, in the present study, the PTV was divided into PTV_Head,

PTV_Chest, PTV_ABD and PTV_Pelvis. For treatment planning, 4 irradiation isocenters were used, each aligned with one of the specified PTV divisions.

Treatment planning was performed using the Eclipse 16.1 planning system, with 6 MeV energy and the AAA calculation algorithm. The dose prescription aimed for a coverage of 12 Gy in 90% of the volume, with the following maximum doses for the OARs: 9 Gy to the lenses, a mean dose of 8 Gy to the lungs, a mean dose of 10 Gy to the kidneys, and a maximum total dose of 125%. No constraint was defined for the liver, which was solely considered to ensure that the point of maximum dose does not fall within this region. The parameters D110% (the minimum dose to 110% of the volume), D2% (the minimum dose to 2% of the volume), and Dmax (the maximum dose within the treatment volume) were also evaluated as part of the planning process.

2.3 DOSIMETRIC EVALUATION METHODOLOGY

Historically, dose rate has been an important dosimetric parameter in TBI treatments because of its link to interstitial pneumonitis (IP), which is the main toxicity associated with Total Body Irradiation (TBI) [5]. Peters, Taylor, and Turner (2015) found that IP was linked to mean lung doses above 10-12 Gy. In another study on factors related to IP after bone marrow transplants, it was observed that dose rate has no significant impact; rather , the mean dose was the primary risk factor [6]. Finally, another study concluded that dose rate only affected IP when total lung doses were above 9 Gy, with no impact at lower total doses [7]. Since we're optimizing for a mean dose of 8 Gy, dose rate won't be evaluated in this protocol.

It is a highly recommended practice to perform a dosimetric evaluation of the planned treatment plan prior to irradiating the patient. Several devices can be used for this evaluation, including planar arrays of detectors. For this study, two planar arrays were used: Matrixx FFF from IBA and Portal Dosimetry from Varian.

To perform the measurement in these devices, a predicted plan was created using a tool called the Eclipse planning system program. For this study, the predicted plan contains the planar distribution of the planned dose for a given treatment isocenter.

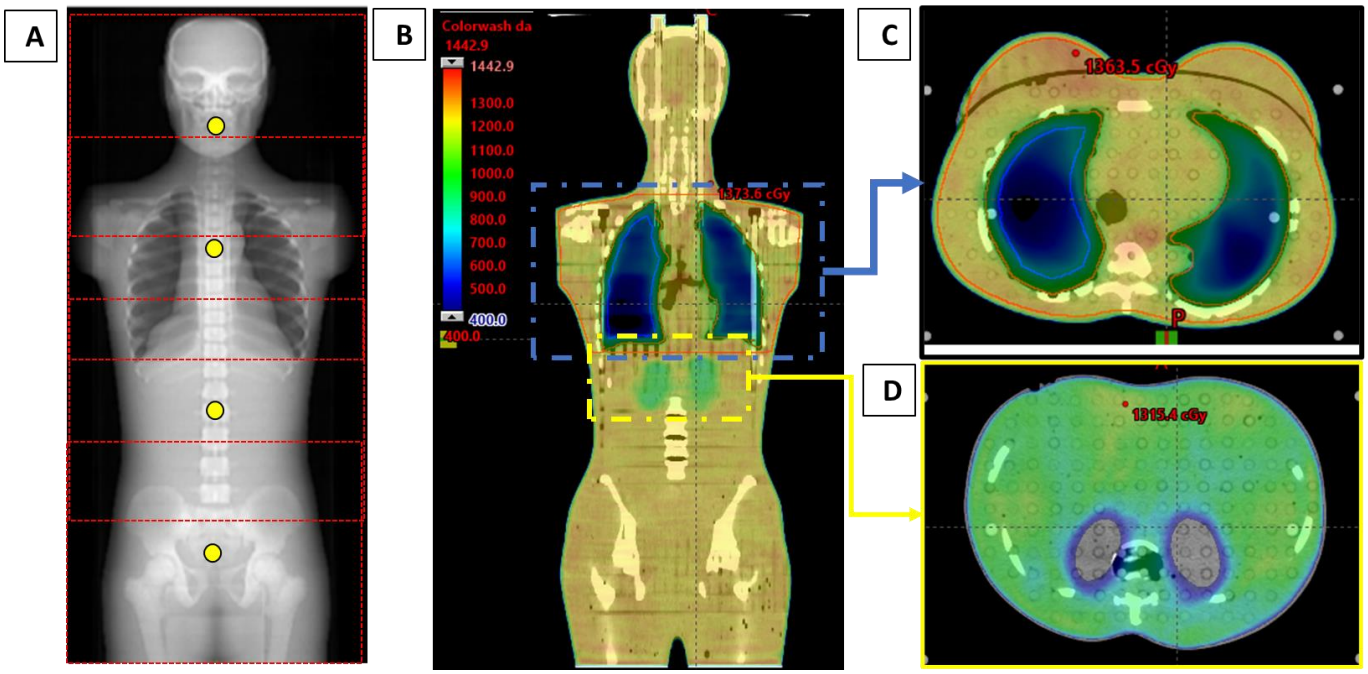
Once the predicted plan has been generated for each detector and for each isocenter, it is possible to perform the quality control measurement. The detectors are aligned to the treatment isocenter and the irradiation process occurs in a similar way to the patient treatment, irradiating the planned beam directly on the detector.

The distribution was evaluated using gamma analysis. Gamma analysis is commonly used to assess the equivalence of the predicted dose with the measured dose [10]. Gamma analysis is a percentage assessment of the percentage of total points in the predicted dose map. It verifies for each point whether within a certain distance (e.g. 3mm) for a certain acceptable variation of the delivered dose (e.g. 3%) a certain percentage of the values (e.g. 95%) are within the criteria. For the present work, a 3%/3mm analysis was performed on the dose distribution.

3. RESULTS

In Figure 2A, it is possible to observe the schematic arrangement of the isocenters used, as well as visualize the achieved dose distribution (Figure 2B). The planning yielded the following results: the values of D110%, D2%, and Dmax were 107%, 105%, and 115% respectively. The mean dose in the lungs was 6.69 Gy and for the kidneys, 9.38 Gy (Figure 1C and 1D). In the lens, the maximum dose was 8.95 Gy. The achieved parameters agree with those presented in the literature [6]. Our study reports a mean lung dose that is lower than the 9.31 to 10.03 Gy range reported in the literature [9,10], which is considered a favorable outcome. Thus, it can be considered that the achieved planning is reasonable for application in a treatment.

Figure 2: (A) Topogram of the phantom, where it is also possible to observe the arrangement of the isocenters used. (B) Visualization of the planned dose distribution. (C) Cross-section of the thoracic region to emphasize the ability to reduce the dose to the lungs, same scale as in B. (D) Cross-section of the abdominal region, where renal sparing can be observed. The minimum dose shown (in blue) is 10 Gy.



Source: The Author (2024).

After the approval of the treatment plan, the predicted plans were constructed, and quality assurance was performed. All plans met the 3%/3mm gamma analysis criteria with 95% tolerance, as shown in Table I.

Table 1: Results for patient-specific quality control for each of the treatment isocenters with the two detectors.

Body Regions	Portal Dosimetry®	IBA Matrix®
Head	99,90%	98,20%
Chest	99,90%	99,30%
Abdomen	99,50%	97,30%
Pelvis	99,90%	98,70%

The results from the portal dosimetry showed better performance compared to the IBA Matrix. This difference may be due to the influence of the treatment table or the angular dependency in the case of the IBA Matrix. However, the values obtained for both are consistent with acceptable results for patient-specific quality assurance and align with values already published in the literature for both portal dosimetry [8] and the IBA Matrix [11].

4. CONCLUSIONS

The planning of Total Body Irradiation (TBI) using Volumetric Modulated Arc Therapy (VMAT) was successfully completed for the CIRS Adult Female models. Patient-specific quality control, performed with both Portal Dosimetry® and IBA Matrix® detectors, confirmed that the planned dose parameters were achieved satisfactorily. All plans met the 3%/3mm gamma analysis criteria with a 95% tolerance, indicating reproducibility between the planned and delivered dose. Overall, the results suggest that VMAT for TBI is effective and can be considered a viable alternative to traditional methodologies, offering improvements in treatment accuracy and potential cost reductions.

In TBI clinical treatments, other factors, such as patient positioning, are also essential. Some studies demonstrate the use of special tables to facilitate treatment for patients over 150 cm tall. Regarding the immobilization system, the literature points to the use of devices like vac-fix, masks, and indexed positioning aids. However, the choice of devices depends both on available resources and on the need for dose precision and reproducibility of patient positioning. Therefore, studies are ongoing to better understand these characteristics and improve treatment protocols.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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