BJRS

BRAZILIAN JOURNAL
OF
RADIATION SCIENCES
11-01A (2023) | 01-13 | e2178

Assessment of dose heterogeneity in TBI using the thorax of the anthropomorphic Alderson-Rando phantom and TLDs in two different setups

Rodrigues[a], F. G. F.; Nolasco[b], A. V.; Meira-Belo[c], L. C.;

Silva[c], C. R. E.; Fonseca[a] T. C. F.

[a] *Universidade Federal de Minas Gerais. Av. Pres. Antônio Carlos, 6627 - Pampulha, Belo Horizonte - MG, Brazil*

[b] *Instituto de Radioterapia São Francisco. Rua Itapagipe, 762 - Concórdia, Belo Horizonte - MG, Brazil*

[c] *Centro de Desenvolvimento da Tecnologia Nuclear. Av. Pres. Antônio Carlos, 6627 - Pampulha, Belo Horizonte - MG, Brazil*

fernandonrufop@hotmail.com

ABSTRACT

Total body irradiation (TBI) is a treatment modality of radiotherapy. It can be used for immunosuppression of transplanted patients or for metastatic protocols. In this study, TBI was performed using the anthropomorphic Alderson-Rando phantom filled with thermoluminescent dosimeters (TLDs) and irradiated with a 6 MV photon beam from the Elekta linear accelerator in two different setups, one at the hospital São Francisco, BH, MG and second at the hospital Santa Casa in Lavras, MG. The dose distribution in the left and right lungs was estimated, analyzed, and compared with results from the literature. Our results showed that dose homogeneity is more adequate with dual-field irradiation.

Keywords: **Total Body Irradiation, Radiation Dosimetry, Radiotherapy, Thermoluminescence.**

ISSN: 2319-0612
DOI: https://doi.org/10.15392/2319-0612.2023.2178
Submitted: 2022-11-28
Accepted: 2023-06-07

1. INTRODUCTION

Total body irradiation (TBI) is a method of radiotherapy that consists in the total body irradiation of a patient in case of cancer. This technique is used in disseminated tumors or in cases of immunosuppression in patients with leukemia to minimize rejection non-hodgkin's lymphoma. Generally, the total body radiation dose is divided into six fractions at six-hour intervals, twice a day. This procedure is based on the redistribution of the individual cell cycle, taking into account the phase in which cellular radiosensitivity is greatest, i.e. the mitotic phase of the cell. In this way, it is possible to inactivate the patient's tumor cells grow or, in the case of immunosuppression, to perform a satisfactory bone marrow transplant [1-2].

The International Commission on Radiation Units and Measurements recommendations in Publications 50 and 62 establish guidelines a maximum uncertainty of 5% and a gradient between -5% and +7% in the Planning Target Volume (PTV). Other organizations give values that differ from the limits set by the ICRU, such as the American Association of physicists in Medicine Guidelines (AAPM-report 17) and the Netherlands Commission on Radiation Dosimetry (NCS-report 34), which discuss the difficulties in setting deviations within 10% of the PTV in TBI and also believe that it is consistent to set the dose to the lung between (60-80)% of the planned dose. One of the main difficulties in TBI is to achieve a homogeneous dose in all irradiated organs [3]. These difficulties in the dose delivered in the organs is due mainly to the different experimental irradiation arrangements that are possible and proposed in TBI in different facilities [1-3]. A wide variation of parameters, e.g., positioning, gantry angle, source-to-surface distance (SSD), body mass, available space, and equipment technology, are specific factors of each institute and hinder the reproducibility of this modality.

Zarghani *et al* show a bibliographic review on the TBI technique taking into account the position, distances, equipment, etc. However, the authors pointed out that the evidence for choosing the most appropriate therapy is indeed the limit to the technological and instrumental availability of each center, which makes it very particular. In particular, the lungs have a low tolerance dose limit, so dosimetry studies are needed to optimize dose distribution in TBI for radiosensitive organs such as the lung [1-4]. Treating the entire body is a difficult task for many reasons, including the size of the patient compared with the size of the conventional radiation field and the heterogeneous tissue composition of the body, among many other parameters. Usually, in a TBI procedure a new set-up is required due to the reference protocol used in the different radiotherapy centers. Therefore, TBI is a technique that can be adapted to any facility with nonstandard clinics, equipment, and treatment rooms [5]. According to Studinski *et al*, a variety of strategies have been studied, proposed and reported in literature in order to improving and keeping the uniformity of practice. They reported a survey from different radiotherapy centers in Canada and several inadequacies of the TBI treatment. Another factor considered by the authors, were the field size used and the differences in the dose delivered for same modality between different radiotherapy centers, all these may be resulting in a high dose variation for the same treatment.

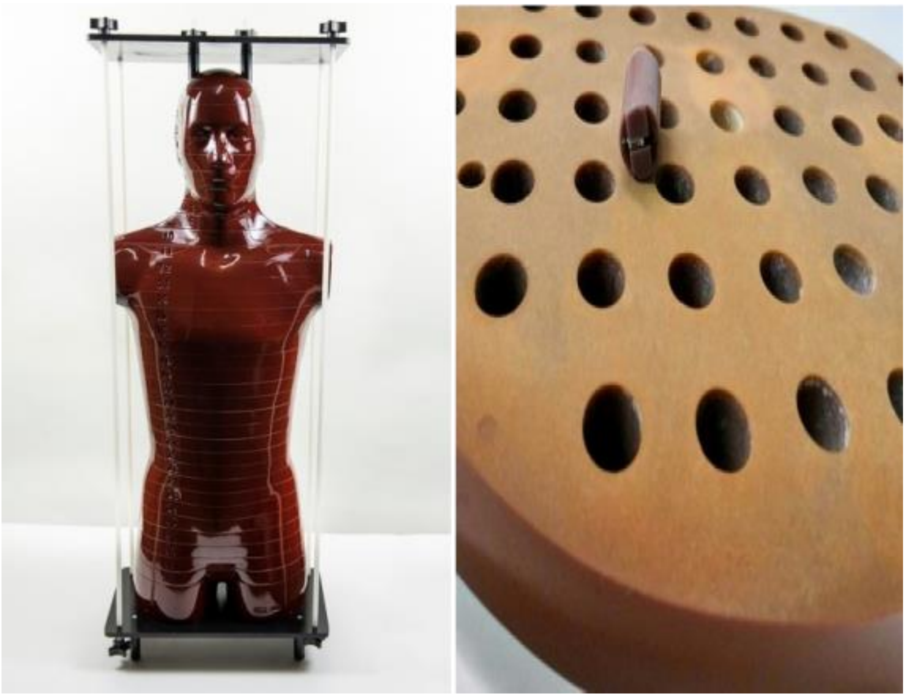
Due to the dose heterogeneity, because of the large irradiation fields set, a more detailed study of the dosimetric parameters, using physical phantoms and radiation detectors are needed to promote and/or ensure the quality of TBI treatments. Several papers published in literature used physical phantoms to study the variation of absorbed dose in different organs [7-10]. The thoracic region of the phantom has always been the subject of various scientific investigations because of its sensitive to ionizing radiation, and in TBI protocol it is important to accurately determine the dose homogeneity in the lungs to minimize the occurrence of adverse events such as pneumonitis [8,9,16].

Thermoluminescence detectors (TLDs) made of magnesium-and titanium-doped lithium material (LiF:Mg, Ti) with a thickness of 0.9 mm and a diameter of 4.5 mm and when exposed to a radiation field, it can detected the absorbed dose. Due to their good response for dosimetric studies, TLDs and phantoms are often used in experiments to estimate and study the dose distribution in several types of treatments [11-14]. The detectors must be calibrated before its use. This means that they are exposed to a reference energy beam quality to evaluate the homogeneity response and linearity, among other parameters. They are qualified and quantified for use in a wide range of dosimetric tests, minimizing the uncertainties that arise [15].

In this present study, the Alderson-Rando physical phantom was used to mimic the absorbed dose delivered to the target organs according to two specific protocols. The phantom consists of tissue similar to human tissue in terms of density, elemental composition and anthropomorphic geometry. The phantom contains representative cavities that house radiation detectors and allow dosimetric studies of various diagnostic procedures and therapies using ionizing radiation. Here, the TLDs were calibrated at the calibration laboratory of the Nuclear Technology Development

Center (LCD /CDTN) in BH, MG. As an exclusion criterion chosen by the authors, variations in the response of the TLDs above ±10% were disregarded in this work. Figure 1 shows the male Alderson-Rando phantom and a slice of his body showing the cavities for the detectors. The results of this work allow investigating the heterogeneity of the absorbed dose using TLDs insert in the lungs regions of the male Alderson-Rando phantom subjected to the TBI treatment modality. Two different scenarios were proposed and experimental irradiation were performed in the radiotherapy center of the Hospital São Francisco, BH, MG and the Hospital Santa Casa in Lavras, MG. The individuality of each facility motivates this study in which has as main goal to configure, evaluate and to propose the most suitable and appropriate protocol for both radiotherapy center.

Figure 1: *Phantom Alderson-Rando male and slices*



Source: https://rsdphantoms.com

2. MATERIALS AND METHODS

Two different scenarios were proposed for the experimental protocol in the hospitals. At Hospital São Francisco (first setup), the Alderson-Rando phantom was placed on the floor of the treatment room under the vacuum bag which gives the maximum distance between the gantry and the phantom, of 260 cm. In this experiment, the phantom was irradiated in a single field only in its right side. The beam quality irradiation was at 57.8º angle and pointed towards the slice number 16, in the middle of the phantom. At Hospital Santa Casa (second setup), the LINAC accelerator was positioned at 90° in related to the floor of the treatment room. The phantom was placed on a hospital bed at a height of 115 cm and at a source to surface distance of 354 cm. Here, two irradiation setups were performed, in both side of the phantom (left and right). First, the phantom was irradiated in the left side, and after its repositioning another irradiation was performed in the right side. Table 1 shows the parameters set in the irradiation protocols of each radiotherapy centers.

Table 1: Parameters used in each experiments

Parameters	São Francisco	Santa Casa
UM	1000*	1614**
DA (cm)* **	260	354
Time (min)	28.80*	12.35**

*one field irradiation (only right side)

**bilateral irradiation - 3228 MU and 24.70 in total.

*** Distance of axis

Normally, the TBI protocol is calculated using the maximum distance gantry-to-patient and field size available in the treatment room. Thus, to calculate the protocol used in the experiment setup proposed in both hospitals, the Monitor Unit (MU), time of irradiation, the distance gantry-to-phantom, dose fraction were taken into account. For example, adding the distance gantry-to-patient, torso width of the phantom, the prescribed dose, whether the use or not of a shield plate, it is possible to obtained the MU and the time values needed to perform the irradiation.

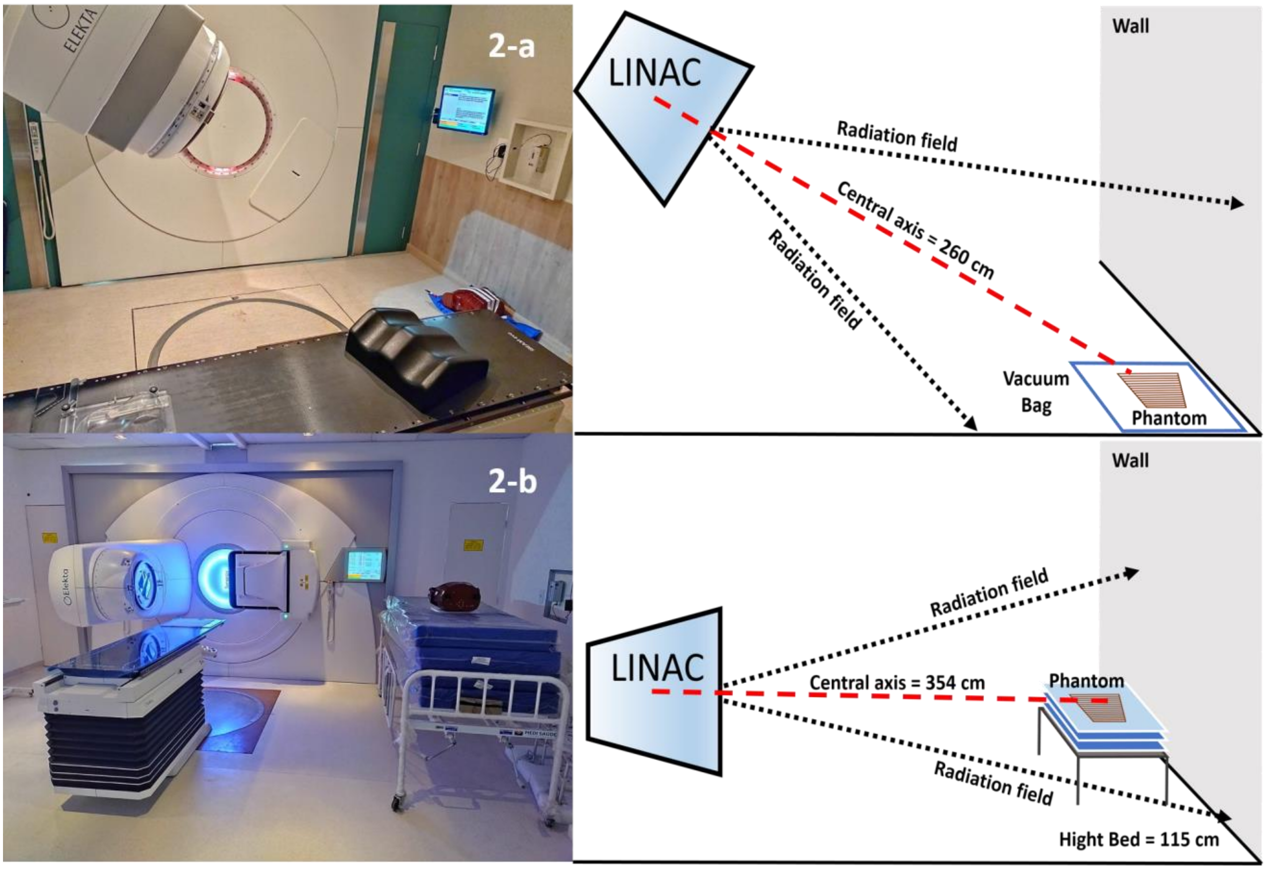
2.1. Experimental Setup Hospital São Francisco

Ten TLD detectors were placed in the cavities of the slices number 11 to 19 which correspond to the lungs region of the Alderson-Rando phantom. The ELEKTA accelerator was used to perform the irradiation with the 6 MV energy beam. The phantom was positioned 260 cm from the source. The gantry was positioned at 57.8º inclined allowing the beam quality to enter the middle of the phantom on the right side (with correspond to the slice number 16) with a single irradiation dose. Figure 2-a shows the picture and a sketch of the irradiation set-up. The maximum field aperture was of 40 x 40 cm², and a dose rate of 1000 MU (Monitor Unit) was applied in a single field for 28.8 min. A total of 190 TLDs were used to measure the energy deposited in the two lungs of the phantoms. After irradiation, the TLDs were removed from the phantom and read using the RISØ TL/OSL reader, model DA-20, of the Dosimetry Laboratory of SECDOS/CDTN, in BH, MG. The absorbed dose was estimated for the right and left lungs of the phantom using the average count rate provide by the reader for each TLD and the calibrate results performed in the reference beam quality.

2.2. Experimental Setup Hospital Santa Casa

Three TLDs were inserted in each cavity of the correspondent lungs, given a total of 135 TLDs for both right and left lungs. The phantom was in the supine position under a 115 cm high bed and at 354 cm from the gantry. The ELEKTA 6MV accelerator was used with a maximum field size and with a beam quality toward direct to the middle (slice number 16) of the phantom. The gantry was rotated to an angle of 90º and a total dose of 3228 MU was given in two irradiation fields for 24.7 min in total (i.e., 24.7 min for the right and left sides). Figure 2-b shows the sketch and a picture of the setup arranged to irradiate. It is noteworthy that the TLDs were not removed after the first irradiation field (right side), but the phantom was rotated on the stretcher and then the second irradiation field was performed with an incidence on the left side of the Alderson-Rando. After irradiation in double field, the TLDs were removed and read with the RISØ reader. The energy deposited in the lungs were analyzed, and the results were compared to the dose measured in the left and right lungs.

Figure 2: *Two Different experimental setups for performing phantom irradiation in TBI. 2-a) Irradiation performed in hospital São Francisco; 2-b) in hospital Santa Casa in Lavras, MG.*



3. RESULTS AND DISCUSSION

The experimental arrangement proposed in the Hospital São Francisco in BH, MG is not the best choice for sub-metabolized patients because of the fragile health status of the patients. The absorbed dose obtained as results for the left and right lungs of the phantom were compared and a difference of 27.41% was observed when compared both, the left against the right lungs values. This deviation was to be expected, since the phantom was irradiated only from the right side and then the higher dose for the right lung was seen.

The experimental arrangement proposed in the Hospital Santa Casa in Lavras, MG seems to be more suitable for the TBI protocol. The results showed a ~2.55% difference between left and right lung, which is within the expected result. Table 2 shows the average absorbed dose (cGy) results obtained in the right and left lungs of the phantom in both experimental TBI protocols performed in the different hospitals.

Table 2: Results obtained for the two experimental setups.

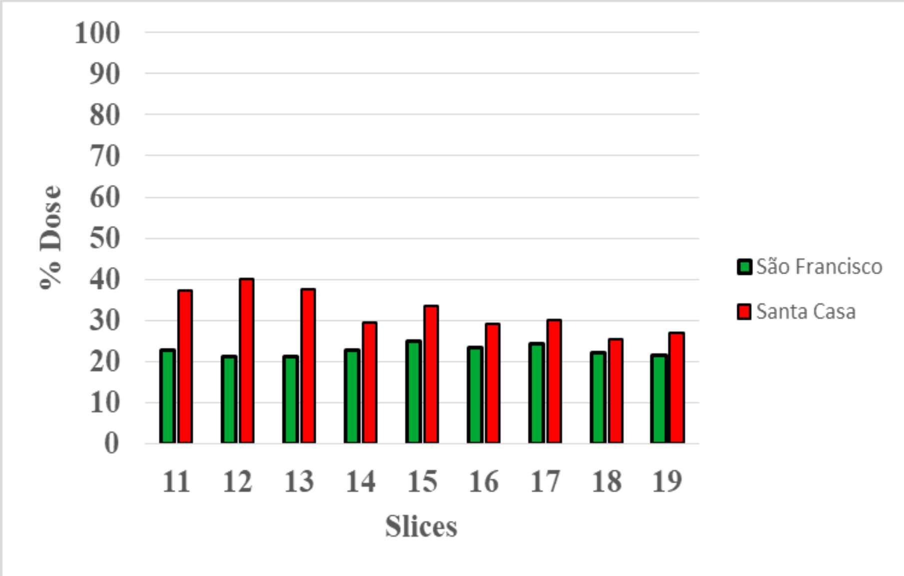
São Francisco	**Right Lung**	**Left Lung**	**Δ (%)**
Average dose (cGy)	(52.57 ± 5.27)	(38.16 ± 3.78)	27.41
Santa Casa	**Right Lung**	**Left Lung**	**Δ (%)**
Average dose (cGy)	(62.65 ± 15.22)	(64.25 ± 15.30)	2.55

In the work of Syh *et al.* published in literature, the authors performed experiments using the Alderson phantom and TLDs. Smaller variations were observed for the range of interest in the lungs when compare the measured and computed data. The authors found less than 2% variation between the planning calculation and the measured dose. They also reported the best combination of the patient setup, for the lung inhomogeneity being the arms closed to the patient torso. This may compensate the energy deposited in the lungs while irradiate the patient. However, in[1,18,19], it is shown that 10% deviation is acceptable for TBI, and furthermore, in[18] even more significant values are observed. It is extremely difficult to achieve deviations of less than 10% without the use of shielding or protections mechanisms [1].

The results obtained for the experiment executed at Hospital São Francisco yielded difference of approximately ~26% in the right lung, whereas at Hospital Santa Casa, a difference of ~31% was obtained in the right when compared to the prescribed dose. Although no protective device was used in both experimental scenarios, these results are consistent with the recommendations of the TBI guidelines [18,19]. In this context, supine positioning seems to naturally promote better lung protection, which is also reported by [2,17]. It was found that the dose heterogeneity in the left and right lungs of the Hospital São Francisco phantom is directly related to the proposed single-field irradiation method. Contrary to the variation found in the experiment carried out at Hospital Santa Casa, due to the irradiation being performed in a double field.

Figure 3 shows the variation of the dose deposited per slice along the phantom in relation to the prescribed dose irradiate in both hospitals. These results were obtained by calculating the average dose deposited in each slice for right and left lungs of the phantom. After the values were divided to the total prescribed dose irradiated. It is possible to observe a scattering of the beam along the size of the phantom, which is due to the large open field.

Figure 3: *Variation of the dose deposited in both lungs per slice of the phantom in relation to the prescribed dose irradiate in both hospitals.*



Source: Author

Although the 6MV beam was directed to slice 16 in both configurations, it is noteworthy that the results from Hospital Santa Casa showed the highest dose value in slice number 12, registering 39% of the prescribed dose. For Hospital São Francisco, slice 15 had the highest dose recording, accounting for ~25% of the dose prescription. However, this can be explained by the greater distance gantry to phantom used in the setup of Santa Casa compared to the setup of São Francisco. The central axis of incidence proposed in the setup of Santa Casa, is different due to the angle rotation of the gantry, as shown in Figure 2. Therefore, the observed differences between the doses deposited along the phantom torso can be associated with the positioning at different distances from the beam source, the geometrical incidence of the beam and the anthropometry of the phantom, in this context, uniformities are to be expected.

A trend of the total dose deposited per slices, showed in Figure 3, may contribute to better understand the setups proposed for each facility and even to be objective of chosen a more efficient protocols of TBI treatments. The use of protection devices may be another strategy to be used in which may adjust the total dose along the lung, mainly for the Hospital Santa Casa in which was observed higher homogeneity dose in the different slices. On the other hand, the results estimated for the experiment executed at São Francisco Hospital showed more homogeneity between the slices. However, the differences shown in Table 2 cannot be neglected because of the heterogeneity between the dose deposited on the left and right side of the phantom's lungs. In addition, studies found in the literature presented results for different configurations and confirming the difficulty of commissioning the single protocol for the application of TBI [6, 8, 10, 20].

4. CONCLUSION

A study of the heterogeneity of the absorbed dose using the TLD insert in the lung slice of the male Alderson-Rando phantom subjected to the TBI treatment modality was performed in two different institutions, the Radiotherapy Treatment Service of the Hospital São Francisco in Belo Horizonte (MG) and Hospital Santa Casa of Lavras (MG), Brazil. Establishing the homogeneity of the dose deposited in the organs is one of the most recommended parameters in the reference documents to carry out an adequate treatment of the patient. Therefore, it is important to emphasize that a single field irradiation does not meet the homogeneity required and is therefore strongly discouraged from a clinical point of view. The results showed that it is possible to obtain a homogeneous dose distribution when the irradiation is performed in two fields. However, it is important to also consider the use of shielding devices for the lungs to minimize the dose to the lungs.

ACKNOWLEDGMENT

The following Brazilian institutions support this research project: Research Support Foundation of the State of Minas Gerais (FAPEMIG), Brazilian Council for Scientific and Technological Development (CNPq) and Coordination for the Capacitation of Graduated Personnel (CAPES). Prof. T. Fonseca is grateful for the financial support provided by CNPq (Process nº 450493/2019-9, 424734/2018-4 and 302990/2021-6) and FAPEMIG (Project APQ-00083-18 Process nº 2070.01.0002992/2018-30, APQ-01388-21, BPD-00963-22).

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