Original Article

Indian Journal of Cancer Education and Research
Volume 7 Number 1, January - June 2019
DOI: http://dx.doi.org/10.21088/ijcer.2321.9815.7119.2

A Dosimetric Study on Indigenously Developed Heterogeneous Thorax Phantom for Radiation Dose Verification in Carcinoma Lung

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Received on 31-1-2019, **Accepted on** 06.03.2019

Abstract

Aim: To design and study the physical and radiological properties of Heterogeneous Thorax Phantom (HTP). *Materials and Methods:* The Computed Tomography (CT) images of thorax were imported on treatment planning system and analyzed for measuring the density of chest wall tissue, lung and soft tissue behind the lung. The mean and standard deviation of these different densities were noted and analyzed. A HTP with similar density distribution was made using slabs of SP34 and pinewood. A plan was made on actual patient's CT scan and on HTP by putting 6 MV photon beam of 10x10 cm^2 field size and source to surface distance of 100 cms perpendicular to the chest wall using anisotropic analytical algorithm with grid size 0.25 cm. Depths for isodose were measured in both the mediums. The CT scan of HTP was taken at three different interface regions. The doses were planned and measured at these three interface regions using ionization chamber. Measured and planned doses were compared and analyzed. *Results:* The mean density of the chest wall, lung and soft tissue were found to be 0.94, 0.28 and 0.98 gm/cc respectively on patient's CT scan, while 0.99, 0.27 and 0.99 gm/cc respectively in HTP. Variation in planned dose and measured dose on HTP at 6 cm, 10 cm and 18 cm depths were found to be 0.47%, 0.81% and 2.4%. *Conclusion:* Phantom mimicking thorax site along with advanced third generation Monte Carlo based algorithms which are based on biological dose calculation should be used for more accurate dose calculation.

Keywords: Heterogeneous Phantom; Slab-Pinewood-Slab Phantom; Third Generation Algorithm, Monte Carlo, Across XB; Monaco.

How to cite this article:
Virendra Bhandari, Saurabh Karnawat, Ashar Iqbal Lodi et al. A Dosimetric Study on Indigenously Developed Heterogeneous Thorax Phantom for Radiation Dose Verification in Carcinoma Lung. Indian J Canc Educ Res. 2019;7(1):13-18.

Introduction

Lung cancer is one of the commonest cancers and cause of cancer related deaths all over the world and is responsible for nearly one cancer death in five (1.59 million deaths, 19.4% of the total) [1]. In India, lung cancer constitutes 6.9 per cent of all new cancer cases and 9.3 percent of all cancer related deaths in both sexes, the highest reported incidence in India is in Mizoram in both men and women [2]. Radiation therapy in cases of carcinoma lung is an important modality of treatment and thorax is a complex site for radiation delivery due to different medium densities regions e.g bones, lung, air, etc. [3] and presence of other organs such as heart, oesophagus. Thorax site being a heterogeneous medium pose a challenge for accurate dosimetric calculations and radiation delivery. The precise planning and dose delivery ensures that we get the full benefit of radiation with minimal impact on other body parts i.e. Organ At Risk (OAR) and maximal permissible dose to the tumour. The dose delivery calculations on a commercial treatment planning systems (TPS) are done with the help of algorithms namely Analytical

Anisotropic Algorithm (AAA), Collapsed Cone Convolution algorithm, Pencil Beam Convolution algorithm which are not that accurate with dose calculations in complex medium like chest [4-7]. For more accurate and precise calculations, Monte Carlo (MC) code based algorithms Monaco, Acuros XB (AXB) were introduced [8-10]. To verify the dose distribution accuracy phantoms are used. Most commonly used are water phantom or water equivalent phantom which are homogeneous in nature [11-13]. So, in order to achieve better dose distribution accuracy heterogeneous phantoms should be used with advanced algorithms [14]. This study has been carried out to evaluate the dose calculated in chest wall-lung interface and dose measured in the similar kind of medium by developing a chest phantom mimicking the thorax and to verify patient specific Quality Assurance using the same.

Materials & Methods

CT scan with 3 mm slice thickness of 20 patients were performed by Siemens SOMATOM Definition AS Scanner (Siemens Medical Systems, Germany). CT set for all the patients were imported on TPS Eclipse version 13.7 (Varian Medical Systems Pvt. Ltd., Palo Alto, California, USA). These CT images were for radiotherapy planning purpose for the concerned patients. These images were analyzed for measuring the density of chest wall tissue, lung and soft tissue behind the lung. The mean and standard deviation of these different densities were noted and analyzed. Also the mean and standard deviation of chest wall thickness, lung separation and soft tissue behind the lung were measured. Keeping the above data as standard a heterogeneous phantom was made using slabs of SP34 (IBA Dosimetry GmbH, Schwarzenbruck, Germany) with dimensions 30x30x1 cm^3 and pinewood slabs cut in the dimensions of 20x30x2 cm^3. To design HTP 5 slabs of SP34 were used to represent 5 cm of chest wall, 7 slabs of pinewood were used to represent lung region and again 10 slabs of SP34 were used to represent thickness of soft tissue behind the lung. The SP34 slab is made up of polystyrene (98%) and titanium oxide (2%) which has a density of 1.045 gm/cc and that of pinewood slab was 0.30 gm/cc. In this way a heterogeneous phantom named as HTP was prepared (Fig. 1). CT Scan with 3 mm slice thickness were done for HTP as well. The CT images were imported on Eclipse TPS. First five slabs volume were marked as chest wall, next seven pinewood slabs were marked as lung and the remaining 10 slabs of SP34 were marked as soft tissue behind the lung. Hounsfield Unit (HU) were measured at multiple points in each of these three volumes created. Density was calculated using these HU numbers using the formula; Density = (1000+HU)/1000 [15]. CT data set of one of the patient was chosen for planning purpose whose average chest wall thickness was 5 cm, lung separation was 14 cm and thickness of the soft tissue behind lung was 10 cm. One plan was made on this patient's CT data set by putting 6 MV photon energy beam of 10x10 cm^2 field size and Source to Surface Distance (SSD) of 100 cms perpendicular to the chest wall surface. The plan was normalized for 100% dose as maximum dose in the entire volume which came at the depth of 1.5 cm. Another plan with same field size and SSD was made on CT images of HTP having beam perpendicular to the phantom's surface. This plan was also normalized with maximum 100% dose in the volume. Both the plans were created by using AAA with grid size 0.25 cm. Depths for isodose lines of 100%, 90%, 80%, 70%, 60%, 50% and 40% were measured in both the plans (Figs. 2,3) and were compared with each other. The CT scan of HTP was repeated thrice for 3 different interface regions using ion chamber within it viz. Ion chamber at position A (chamber at slab-pinewood interface), ion chamber at position B (chamber at 12 cm depth from the surface of the phantom i.e. within the pinewood) and ion chamber at position C (chamber at pinewood-slab interface). The arrangement of ion chamber at different positions was made possible by replacing the pinewood slab with specially designed pinewood slab of the same dimension (i.e. 20x10x2 cm^3) having cavity at its centre for the thimble chamber (IBA Dosimetry GmbH, Schwarzenbruck, Germany). These positions mimicked the soft tissue-lung, lung, and lung-soft tissue interfaces. The doses at the soft tissue-lung interface and slab-pinewood interface were measured. Similarly doses at the lung-soft tissue behind lung interface and pinewood-slab interface were measured. The dose within the lung and pinewood were also measured at 12 cm from the surface. HTP with ion chamber at position A was set on the LA couch with 100 cm SSD and matching the machine's isocenter at the surface of phantom in such a way that the central axis of the beam would go through the centre of ion chamber cavity. The plan done on phantom with chamber at position 1 was loaded for delivery. Cone Beam CT (CBCT) was taken for accurate positioning of the phantom and chamber within it. After verifying the setup plan was delivered and the

dose was measured. Similar process was repeated for measuring the dose at position B and position C (Fig. 3); The planned and measured doses at all the three positions were compared and analyzed.

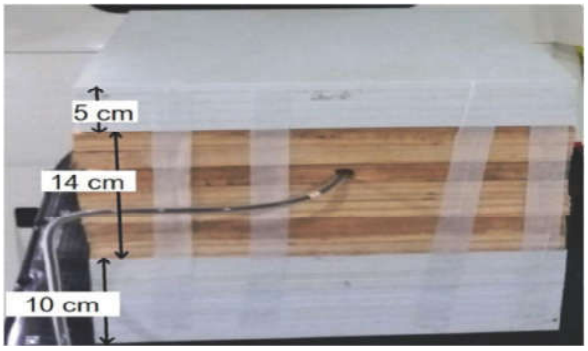

Fig. 1: Schematic representation of HTP

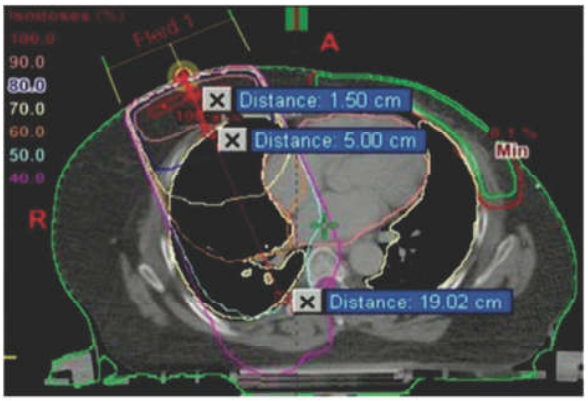

Fig. 2: Isodose curves at different depths in CT slice of patient

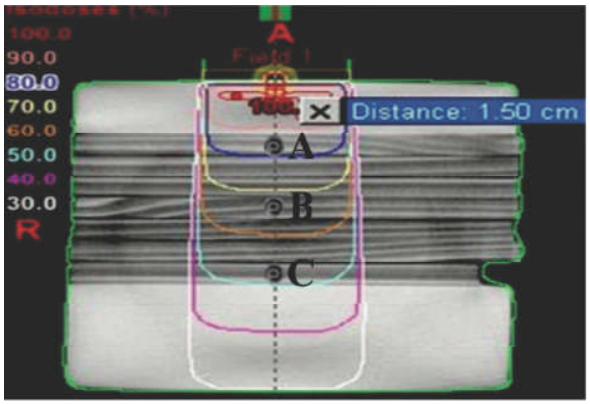

Fig. 3: Isodose curves at different depths along with different positions (A, B, and C) for placement of ionization chamber in HTP

Results

The mean density of the chest wall, lung and soft tissue behind the lung were found to be 0.94, 0.28 and 0.98 gm/cc respectively, while that of SP34 slab and pinewood slab were found to be 0.99 and 0.27 gm/cc respectively (Tables 1 and 2). Isodose curves for chest and the HTPs were almost similar for 100%, 90% and 80% depth dose. Isodose curves for 70% and 60% depth dose were more in actual patient compared to the HTP and the isodose curves for 50% and 40% dose were again similar for both (Table 3); the variation in planned dose and measured dose on HTP at 6 cm, 10 cm and 18 cm depths were found to be 0.47%, 0.81% and 2.4% respectively (Table 4).

Table 1: Hounsfield unit (HU) and density measurement of chest wall, lung and soft tissue

No of points in given medium	HU of chest wall	HU of lung	HU of soft tissue
1	-71	-683	-26
2	38	-694	-28
3	-120	-671	-94
4	-122	-743	-3
5	-100	-669	70
6	-115	-725	79
7	-30	-713	-71
8	-101	-704	-107
9	-113	-701	-72
10	53	-722	-56
11	46	-679	-106
12	10	-688	74
13	-47	-744	44
14	-64	-701	-80
15	-90	-724	-42
16	-73	-717	-59
17	-88	-798	63
18	-40	-789	-38
19	-78	-716	36
20	44	-701	21
Mean HU	-53.05	-714.1	-19.75
Density (g/cc)	0.94	0.28	0.98

Table 2: Hounsfield unit (HU) and density measurement of pine wood and SP34 slabs

No of points in given medium	HU of pine wood slab	HU of SP34 slab
1	-732	-36
2	-748	5
3	-730	11
4	-721	-18
5	-715	11
6	-740	-12
7	-709	13
8	-720	4

9	-749	-19
10	-722	-17
11	-731	-20
12	-733	8
13	-735	13
14	-718	15
15	-721	2
16	-713	15
17	-717	-36
18	-719	-5
19	-743	-6
20	-755	-35
Mean HU	-728.55	-5.35
Density (g/cc)	0.27	0.99

Table 3: Isodose depths in CT images of the patient and HTP

Isodose lines (%)	Isodose depth in patient (cm)	Isodose depth in S-P-S phantom (cm)
100	1.5	1.5
90	4.24	4.16
80	7.24	7.13
70	11.82	10.4
60	16.38	14.67
50	19.6	19.28
40	23.71	23.98

Table 4: Dose at different depths in CT image of the patient and HTP

Depth (cm)	Planned dose on TPS (cGy)	Measured dose on LA (cGy)	% variation
6 cm	83.8	83.4	-0.47
10 cm	73.6	74.2	0.81
18 cm	54.1	55.4	2.4

Discussion

The radiation therapy of carcinoma lung is a challenging task as it requires a high precision. Thorax site has different density patterns in its volume e.g chest wall consists of soft tissue which has a density of approximately 1 gm/cc, lung cavity with density near to that of air and again soft tissue behind the lung. The interaction of radiation with such a region with complex density pattern is different as it is elsewhere because of high density variation. Because of this the dose calculation and delivery becomes a tedious task. If adequate coverage of the tumour volume is not obtained and optimum dose is not delivered then it may lead to underdosing/overdosing and may lead to residual disease or recurrence.

Algorithms for dose calculation plays a pivotal role in precision radiation therapy planning and dose delivery. If a better algorithm is chosen which calculates the dose considering the heterogeneity with different density gradient then it will calculate dose more accurately. Monte Carlo based algorithms such as AXB, Monaco, etc. are latest algorithms which takes heterogeneity into account are more accurate for dose calculation in such mediums where there different density regions. If such new algorithms are used for panning then it will calculate the dose at soft tissue lung interface region more accurately and hence it will lead to better dose estimation at the edge and will also improve the treatment outcome.

Liang et al. compared AAA with Acuros XB and concluded that PTV dose was overestimated by AAA. [16]

Gurjar et al. proved that AAA doesn't calculate the dose accurately in heterogeneous medium as compared to homogeneous medium [17]

However, if newer Monte Carlo based algorithms are not available at the centre in the TPS and second generation algorithm like AAA is available then the drawbacks of such an algorithm should be kept in mind and appropriate corrections should be made at the time of planning which will help in accurate dose delivery to the target and it can also avoid underdosing or overdosing.

Current study has evaluated the dose calculated by AAA and its comparison with measured dose and its implementation in approving dose planned. The study was carried out by using heterogeneous chest phantom with same density pattern as of chest region after confirming the similarity in density pattern in both the media i.e. HTP and actual chest region.

The mean densities of soft tissue of the chest wall, lung and the soft tissue behind it were found to be 0.95, 0.28 and 0.98 gm/cc respectively. The phantom (SP34) which is routinely used for patient specific QA, is made up of water equivalent material and have an average density of 1.034 gm/cc which is similar to that of chest wall region and also to the soft tissue behind it. Similarly the calculated density of pinewood slab is 0.30 gm/cc which is nearly equal to density of the lung region. In this way HTP is representing the density pattern with equivalent thickness regions of each density type as the chest i. e. chest wall-lung-soft tissue. Therefore choice of using HTP for dose calculation purpose for chest region is rational.

Now, the selection of HTP is important as compared to using a phantom with uniform density across its volume.

The radiological property of HTP and the chest

site was checked for isodose depths with a beam of 6 MV photons with field size 5x5 cm2, Source to Surface Distance (SSD) of 100 cm and perpendicular to the surface in both the cases.

The isodose depths of 100% and 90% have almost similar depths in both the plans (one on the patient's CT image and another on the HTP) while the 80%, 70% and 60% have different depths in both the plans, this is significantly because density of the lung is low, hence there is low backscattering of electrons and also the density of the slab is slightly higher than the chest wall and then again 50%, 40% isodose depths matches.

Dubey et al. reported that if phantoms resembling the actual chest are used for QA in IMRT plans then it would yield better results [18].

The planned doses which were calculated by AAA at the interface regions and in the middle of the wood region were compared with the measured doses at the concerned points. The results indicates that AAA over-calculates the dose at interface region, it is because number of secondary electrons produced in SP34 are higher and number of backscattered electrons in the wood are lower due to low density of the medium, while the AAA under calculated dose at wood-SP34 region and in the wood.

Rana [19] have published a study which shows AXB is better than AAA for dose calculation in heterogeneous medium.

The difference in calculated doses and measured doses is a good reference in understanding the actual dose distribution pattern in carcinoma lung cases, it is different from what we see on TPS as calculated by AAA.

So, understanding from the study, it is explainable that if PTV is the target, L is the lung region and S is the soft tissue region (Fig. 4).

What we see here is AAA calculates lesser dose at point P1 and greater dose at point P2. If the plan is approved with 95% of the planned dose coverage then based on the results of this study, approximately 2.5 % dose will be higher at the point P1 and lesser at the point P2 as compared to what we see on the TPS.

So, the dose at P1 is not a problem if it is lesser than 105% to <2 cm^2 area and higher than 95% dose as the maximum dose at hotspot acceptable as per ICRU-83 is 105% to a 2 cm^2 area. But if the planned dose at P2 is 95% then there is a high probability that it will receive lesser dose and if the lesser dose covers the bigger target then it might result in underdosing. Therefore, based on the current study, it is highly recommended that the minimum of 97% or above dose coverage should be achieved at the region which is similar to P2 on the TPS as per the calculations shown by AAA, so that at least 95% plus dose can be practically delivered to the whole PTV.

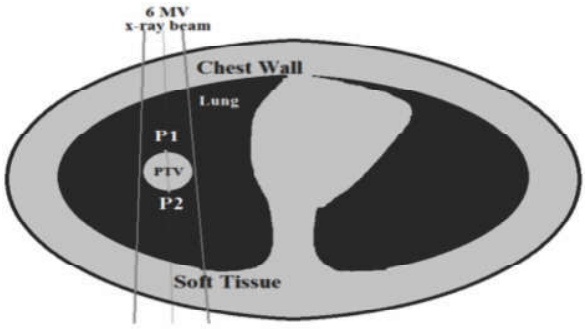

Fig. 4: Schematic diagram of chest region

Conclusion

The current study was done by using S-P-S heterogeneous chest phantom for the the verification of doses calculated by AAA at interface regions. As the density and isodose depths profiles of the HTP were found to be equivalent to the actual chest region. Thus the use of heterogeneous phantom for patient specific QA is justified. Based on the results of current study it can be concluded that that the heterogeneous chest phantom should be used for verifying the dose calculated in the chest site planning instead of homogeneous phantom.

Besides heterogeneous phantom there is a need of Monte Carlo based algorithm which can calculate accurate dose at the interface region. Hence newer algorithm like acuros XB should be used for dose calculation in heterogeneous medium instead of AAA.

Combination of such heterogeneous phantom and Monte Carlo based algorithm will definitely improve the patient specific QA practices and thus help in improving treatment outcome.

Sources of support: NIL

Ethical Issues: NIL

Conflicting Interest : NIL

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