Accuracy of a Novel Head and Neck Phantom for Heterogeneous Media Verification Using an Irregular Field Algorithm

Michael Onoriode Akpochafor,1 Akintayo Daniel Omojola,2 Muhammad Yaqub Habeebu,1 Samuel Olaolu Adeneye,1 Moses Adebayo Aweda,1 Chieloka Chinazom Iloputaife,1 Temitope Aminat Orotoye,1 Abayomi Emmanuel Opadele1

1Department of Radiation Biology, Radiotherapy, Radiodiagnosis and Radiography, Lagos University Teaching Hospital, Faculty of Medicine, Iddi-Araba, Lagos, Nigeria
2Department of Radiology, Medical Physics Unit, Federal Medical Centre Asaba, Delta State, Nigeria

Abstract

Objectives: The treatment outcome in patients can be improved with a fast and accurate treatment planning system (TPS) algorithm. The aim of this study was to design a novel head and neck phantom and to use it to test whether the accuracy of the irregular field algorithm of the Precise Plan 2.16 (Elekta Instrument AB, Stockholm, Sweden) TPS was within ±5% of the International Commission on Radiation Units and Measurements (ICRU) limit for homogenous and inhomogeneous media by rotating the Elekta Precise linear accelerator gantry angle using 2 fields.

Methods: A locally designed acrylic phantom was constructed in the shape of a block with 5 inserts. Acquisition of images was performed using a HiSpeed NX/i computed tomography scanner (GE Healthcare, Inc. Chicago, IL, USA); the Precise Plan 2.16 TPS was used to determine the beam application setup parameters and an Elekta Precise linear accelerator was used for radiation dose delivery. A pre-calibrated NE 2570/1 Farmer-type ion chamber with an electrometer was used to measure the dose. The mimicked organs were the brain, temporal bone, trachea, and skull.

Results: The maximum percentage deviation for 10×10 cm and 5×5 cm inhomogeneous inserts was 1.62 and 4.6, respectively, at a gantry angle of 180°, and that of the 10×10 cm homogeneous insert was 3.41 at a gantry angle of 270°. The percentage deviation for only the bone insert (homogeneous) and for all inserts (inhomogeneous) using parallel opposed beams was 2.89 and 2.07, respectively. Also, the percentage deviation between the locally designed head and neck phantom and the solid water phantom of the linear accelerator was 0.3%.

Conclusion: The validation result of our novel phantom in comparison with the solid water phantom was good. The maximum percentage deviations were below the ICRU limit of ±5%, irrespective of gantry angles and field sizes.

Keywords: Irregular field algorithm, ionization chamber, phantom, Plexiglas, solid water phantom, treatment planning system

Cite This Article: Akpochafor M, Omojola A, Habeebu M, Adeneye S, Aweda M, Iloputaife C, Orotoye T, Opadele A. Accuracy of a Novel Head and Neck Phantom for Heterogeneous Media Verification Using an Irregular Field Algorithm. EJMO. 2018; 2(2): 73-78
the fact that measurement-based models can account for
the effect of tissue inhomogeneities on the primary radia-
tion. However, correcting for scatter radiation is difficult
because it depends on field size, beam energy and shape,
and location and density of inhomogeneities.\[9\] In contrast,
model-based algorithms can account for the effect of tis-
sue inhomogeneities on scatter radiation using the density
scaling method or other approaches.\[10-13\]

Several techniques for performing quality assurance of TPS
have been proposed.\[14-17\] Similarly, reduction in errors and
uncertainties during dose calculation plays an important
role in the success of a treatment procedure. The perfor-
manee and quality of any treatment planning system (TPS)
is dependent on the type of algorithm used.\[18-26\]

Treatment planning requires the ability to calculate the
dose to any arbitrary point within the patient for any beam
orientation. The irregular field program, also known as the
area integration algorithm, is well suited for this purpose.
Patient tissue inhomogeneities, beam blocks, and beam
compensators are included in the calculation model. The
irregular field program requires separation of the dose into
primary and scatter components. The primary component
is usually computed and includes transmission through
any blocks and blocking trays, beam compensators, and
patient inhomogeneities. The scatter component is usually
computed and includes presence of blocks, beam compen-
sators, and curvature of the patient, but not patient inho-
mogeneities.\[27-29\]

The concept of this dosimetry of the irregular field program
involves the use of tissue-maximum ratio and scatter-max-
imum ratio, which are analogous to tissue-air ratio (TAR)
and scatter-air ratio (SAR) concepts, respectively. The un-
derlying program equation of the area integration (irreg-
ular field program), which is similar to the external beam
program, is as follows:

\[
\text{Dose Rate} = \text{TRAY} \cdot \text{TRAY}^2 \cdot \text{OUTPUT} \cdot \text{FSC} \cdot \\
(\text{P} \cdot \text{OCR} \cdot \text{QF} \cdot \text{TAR}_0 + \text{SC}) \cdot \\
(\text{SSD} + \text{DMAX} + \text{c})^2
\]

where TRAY and TRAY2 = tray factors
OUTPUT = the output factor normalized to a (0×0) field size
at a distance SAD + DMAX
FSC = the air field size correction dependency factor, which is
computed for equivalent square of the collimator opening
SSD = source-to-surface distance
DMAX = maximum dose
SPD = source-to-point distance of the point of calculation
X and Y = co-ordinates at the depth of the point of calculation
c = correction for the virtual location of the source; c is de-
termined from a plot of the inverse of the square root of
Dm versus distance from the source
QF = the off-axis beam quality factor
OCR = the in-air off-central-axis ratio value
TAR0 = the zero (0×0) field TAR for the slant depth
SC = scatter contribution computed from the field size and
block contours at the level of the point of calculation
p = value of the penumbra, calculated using the Wilkinson
Source Model

This study will focus on verifying the percentage dose ac-
curacy of the irregular field algorithm using homogeneous
and inhomogeneous inserts by varying gantry angles for
given field sizes of 5×5 cm and 10×10 cm. The reason for de-
signing this novel phantom was to compensate for a ready-
made phantom like the Rando Alderson Phantom which is
not available in most radiotherapy centers in Nigeria.

Methods

The in-house designed phantom was made from Plexiglas
with a thickness of 0.33 mm. A plastic-based hardener (all-
plast) was used for holding one slab to another to form a
cube. Plexiglas (dimension, 4×8 feet) was purchased from
a local plastic shop; a part of which was cut using a plastic
cutter into six slabs each of a dimension of 20×20 cm. Five
holes were drilled on one face. Each drilled hole had a di-
ameter of 2.5 cm gummed together using the plastic-based
hardener “allplast”. The phantom block was drilled to hold
a cylindrical rod (13.5 cm) made of Plexiglas to accommo-
date a 0.6 cm³ graphite ionization chamber (NE 2570/1)
and also four holes for the tissue-equivalent mixed chemi-
cals. The center of the chamber was 10 cm from the end of
the block and diagonally displaced by 7 cm from the other
holes. The inferior block of the phantom was drilled to al-
low water flow (Fig. 1a). Percentage compositions by mass
of the tissue equivalent materials were determined at the
Pharmaceutical Technology Laboratory of Lagos University
Teaching Hospital and was used to mimic each biological
tissue (Table 1). The in-house designed phantom was filled

Figure 1 (a, b). Locally designed head and neck phantom with mim-
icked inserts (LT) and CT image (RT).
with water and loaded with the tissue-equivalent materials and scanned using a HiSpeed NX/i computed tomography (CT) scanner. Slices of images were acquired for four different tissue-equivalent materials including the ion-chamber port (Fig. 1b). Images were transported through the Digital Imaging and Communications in Medicine (DICOM) to the Precise PLAN Release 2.16 TPS, where 12 field technique, denoted as beam (BM) 1–BM 12, was used with field sizes of 10×10 cm covering the four inserts and no wedge was used. Gantry angles (in degrees) for the 12 fields were 0°, 22.5°, 45°, 90°, 135°, 157.5°, 180°, 197.5°, 215°, 270°, 315°, and 337.5°, respectively. The total dose for the 12 fields was 100 cGy, and the total monitor unit (MU) was 100 MU. The type of beam used was “simple.” The photon energy used was 6 MV, source-to-axis distance (SAD) was 100 cm, and SSD was approximately 85 cm. The collimator angle was 0°; the upper SAD of the diaphragm was approximately 10 cm and the lower SAD was 10 cm, giving a total area diaphragm size of 10×10 cm. Under modifiers, the tray factor was 1, and no MLC was present. All planned images from the Precise PLAN 2.16 TPS were transferred to the Elekta-Precise linear accelerator for treatment.

A second scan was performed following the same protocol using 5×5 cm fields. The six-field technique, denoted as BM 1–BM 6, was used covering the four inserts and no wedge was used. Gantry angles (in degrees) for the 12 fields were 0°, 45°, 90°, 135°, 180°, 225°, and 270°, respectively. The total dose for the six fields was 100 cGy, and the total monitor unit (MU) was 100 MU. The type of beam used was “simple.” The photon energy used was 6 MV, source-to-axis distance (SAD) was 100 cm, and SSD was approximately 85 cm. The collimator angle was 0°; the upper SAD of the diaphragm was approximately 10 cm and the lower SAD of the diaphragm was 10 cm, giving a total area diaphragm size of 10×10 cm. Under modifiers, the tray factor was 1 and no multileaf collimator (MLC) was present.

A third scan was performed using the same protocol with 10×10 cm field sizes, but the insert was bone only equivalent material (assumed to be a homogenous medium). Acquired images from the CT simulator were also transferred to the Precise PLAN 2.16 TPS through the DICOM. A six-field technique was used, denoted as BM 1–BM 6, covering the four inserts which were uniformly homogeneous with no wedge used. Gantry angles for the six fields were 0°, 45°, 90°, 180°, 225°, and 270°, respectively. The total dose for the 6 fields was 100 cGy, and total MU was 100 MU. The type of beam used was “simple.” The photon energy used was 6 MV; SAD was 100 cm and SSD was approximately 84 cm. The collimator angle was 0°; the upper SAD of the diaphragm was approximately 10 cm and the lower SAD was 10 cm, giving a total area diaphragm size of 10×10 cm. Under modifiers, the tray factor was 1, and no MLC was present. All planned images from the Precise PLAN 2.16 TPS were transferred to the Elekta-Precise linear accelerator for treatment.

Comparison using the Elekta-Precise clinical linear accelerator for bone only (homogenous) and all four (inhomogeneous) inserts was measured using SSD of 85 cm with a 6-MV photon beam to determine variations in percentage deviation.

Similarly, a simple experimental protocol for validation of the algorithm was also performed between the locally designed head and neck phantom and the solid water phantom with SSD of 85 cm. The Elekta-Precise clinical linear accelerator was initially calibrated using a large water phantom, with a 6-MV photon beam to give 100 cGy (1 Gy) at 100 MU with a pre-calibrated NE 2570/1 farmer-type ionization chamber to determine the absorbed dose. Necessary corrections for temperature, pressure, polarization, recombination, etc., were dependent on the ionization chamber response. Absorbed dose at the reference depth was calculated as follows:

$$D_{w,Q} = M_q \times N_{d,w} \times K_{Q_{0}}$$

where $M_q$ is the electrometer reading (charge) corrected for temperature and pressure, $N_{d,w}$ is the chamber calibration factor, and $K_{Q_{0}}$ is the factor which corrects for difference in the response of the dosimeter at the calibration quality $Q$ and at quality $Q_0$ of the clinical X-ray beam, according to the TRS 398 protocol of the International Atomic Energy Agency (IAEA).

Deviation between DC and Dm was obtained using the following equation:

$$\% \text{ Deviation} = \left( \frac{D_c - D_m}{D_m} \right) \times 100$$

where $D_c$=calculated dose $D_m$=measured dose

### Statistical Analysis

Data analysis was conducted using SPSS 16.0 (SPSS Inc, Chicago, IL, USA) Descriptive statistics, one-sample t-test, and unpaired t-test was implored at a 95% level of significance. A p<0.05 was considered to be statistically significant.

### Table 1. Mimicked organ and chemical compositions

<table>
<thead>
<tr>
<th>Mimicked tissue equivalent organ</th>
<th>Chemical Compositions (% by mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>C, H,O, and MgO (52, 25, and 23)</td>
</tr>
<tr>
<td>Temporal bone</td>
<td>C, H,O, MgO, and Ca (40, 27, 23, and 10)</td>
</tr>
<tr>
<td>Trachea</td>
<td>C, H,O, and MgO (14, 15, and 71)</td>
</tr>
<tr>
<td>Skull</td>
<td>C, H,O, MgO, and Ca (35, 30, 20, and 15)</td>
</tr>
</tbody>
</table>
Results

The measured absorbed doses (Gy) for the 12 beams with four inhomogeneous inserts with a field size of 10×10 cm at a gantry angle of 0°, 22.5°, 45°, 90°, 135°, 157.5°, 180°, 197.5°, 215°, 270°, 315°, and 337.5° were 1.000, 1.008, 1.007, 1.012, 1.008, 1.000, 0.984, 1.001, 1.007, 1.009, 1.008, and 0.987, respectively, and the corresponding percentage deviation were 0.00, 0.79, 0.70, 1.19, 0.79, 0.00, 1.62, 0.10, 0.70, 0.89, 0.79, and 1.31, respectively (Table 2).

The measured absorbed doses (Gy) for the six beams with four inhomogeneous inserts with a field size of 5×5 cm at a gantry angle of 0°, 22.5°, 45°, 90°, 180°, and 270° were 0.9894, 0.9920, 0.9694, 0.9560, 0.9864, and 0.9588, respectively, and the corresponding percentage deviation were 1.07, 0.81, 3.61, 4.60, 1.38, and 4.30, respectively (Table 3).

The measured absorbed doses (Gy) for the six beams with the bone only homogeneous for the four inserts with a field size of 10×10 cm at a gantry angle of 0°, 45°, 90°, 180°, 225°, and 270° were 0.9870, 0.9802, 0.9740, 0.9760, 0.9740, and 0.9670, respectively, and the corresponding percentage deviation were 1.31, 2.02, 2.67, 2.46, 2.67, and 3.41, respectively (Table 4).

Using the linear accelerator, a comparison was performed to define the extent of deviation when the irregular field algorithm was computed using only bone for the four inserts with parallel opposed beams (90° and 270°) and using different tissue materials for the four inserts with parallel opposed beams (90° and 270°). The mean dose computed for the two inserts were 0.972±3.16E-4 and 1.021±5.16E-4, respectively. Deviation from the initially calibrated dose of 1 Gy by the water phantom were 2.89% and 2.07%, respectively (Table 5).

Validation was made between the mean dose (Gy) calculated for the locally designed head and neck phantom and that calculated for solid water phantom by directly using the linear accelerator at a gantry angle of 0°. The mean doses were 0.744±5.48E-4 and 0.746±5.16E-4 Gy respectively, and percentage deviation between them was 0.3% (Table 6).

Discussion

The measured absorbed dose (Gy) for the 12 beams with four inhomogeneous inserts with a field size of 10×10 cm at BM 1 (0°) and BM 6 (157.5°) was 1 Gy with deviation of 0, indicating that Dm values at these beams were accurate and similar to DC value of 1 Gy. There was no significant difference in DC and Dm values (p=0.086). The maximum percentage deviation was 1.62 with BM 7 at a gantry angle of 180° (Table 2).

The minimum and maximum percentage deviations with the six beams with four inhomogeneous inserts with a field size of 5×5 cm were 0.81 with BM 2 at a gantry angle of 45° and 4.60 with BM 4 at a gantry angle of 180°, respectively. There was no significant difference in DC and Dm values (p=0.002) (Table 3).

There was a significant difference in the dose value for the

<table>
<thead>
<tr>
<th>Beam</th>
<th>Gantry angle (°)</th>
<th>Mean absorbed dose±SD (Gy)</th>
<th>% Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM 1</td>
<td>0°</td>
<td>1.000±0</td>
<td>0.00</td>
</tr>
<tr>
<td>BM 2</td>
<td>22.5°</td>
<td>1.008±5.774E-4</td>
<td>0.79</td>
</tr>
<tr>
<td>BM 3</td>
<td>45°</td>
<td>1.007±0</td>
<td>0.70</td>
</tr>
<tr>
<td>BM 4</td>
<td>90°</td>
<td>1.012±5.774E-4</td>
<td>1.19</td>
</tr>
<tr>
<td>BM 5</td>
<td>135°</td>
<td>1.008±1.154E-4</td>
<td>0.79</td>
</tr>
<tr>
<td>BM 6</td>
<td>157.5°</td>
<td>1.000±5.774E-4</td>
<td>0.00</td>
</tr>
<tr>
<td>BM 7</td>
<td>180°</td>
<td>0.984±51.962E-4</td>
<td>1.62</td>
</tr>
<tr>
<td>BM 8</td>
<td>197.5°</td>
<td>0.991±5.774E-4</td>
<td>0.10</td>
</tr>
<tr>
<td>BM 9</td>
<td>215°</td>
<td>1.007±64.291E-4</td>
<td>0.70</td>
</tr>
<tr>
<td>BM 10</td>
<td>270°</td>
<td>1.009±0</td>
<td>0.89</td>
</tr>
<tr>
<td>BM 11</td>
<td>315°</td>
<td>1.008±63.509E-4</td>
<td>0.79</td>
</tr>
<tr>
<td>BM 12</td>
<td>337.5°</td>
<td>0.987±0</td>
<td>1.31</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Beam</th>
<th>Gantry angle (°)</th>
<th>Mean absorbed dose±SD (Gy)</th>
<th>% Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM 1</td>
<td>0°</td>
<td>0.989±5.744E-4</td>
<td>1.07</td>
</tr>
<tr>
<td>BM 2</td>
<td>45°</td>
<td>0.992±7.071E-4</td>
<td>0.81</td>
</tr>
<tr>
<td>BM 3</td>
<td>90°</td>
<td>0.969±5.744E-4</td>
<td>3.61</td>
</tr>
<tr>
<td>BM 4</td>
<td>180°</td>
<td>0.956±0</td>
<td>4.60</td>
</tr>
<tr>
<td>BM 5</td>
<td>225°</td>
<td>0.986±8.944E-4</td>
<td>1.38</td>
</tr>
<tr>
<td>BM 6</td>
<td>270°</td>
<td>0.958±10.954E-4</td>
<td>4.30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Beam</th>
<th>Gantry angle (°)</th>
<th>Mean absorbed dose±SD (Gy)</th>
<th>% Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM 1</td>
<td>0°</td>
<td>0.987±0</td>
<td>1.31</td>
</tr>
<tr>
<td>BM 2</td>
<td>45°</td>
<td>0.980±4.083E-4</td>
<td>2.02</td>
</tr>
<tr>
<td>BM 3</td>
<td>90°</td>
<td>0.974±0</td>
<td>2.67</td>
</tr>
<tr>
<td>BM 4</td>
<td>180°</td>
<td>0.976±0</td>
<td>2.46</td>
</tr>
<tr>
<td>BM 5</td>
<td>225°</td>
<td>0.974±0</td>
<td>2.67</td>
</tr>
<tr>
<td>BM 6</td>
<td>270°</td>
<td>0.967±0</td>
<td>3.41</td>
</tr>
</tbody>
</table>
12 beams with four inhomogeneous inserts with a field size of 10×10 cm and that for six beams with four inhomogeneous inserts with a field size of 5×5 cm \((p<0.001)\). The results obtained show that there was more deviation in accuracy with the 5×5 cm field size.

The minimum and maximum percentage deviation with the six beams with bone homogeneous inserts with a field size of 10×10 cm was 1.31 with BM 1 at a gantry angle of 0° and 3.41 with BM 6 at a gantry angle of 270°, respectively. Parallel opposed fields had the maximum dose of 2.67 and 3.41 with gantry angles of 90° and 270°, respectively; the result was similar to that reported by Akpochafor et al.\cite{31} whose maximum percentage deviation at BM 10 (270°) was 3.95 using similar algorithm with field size of 25×25 cm. There was no significant difference in \(D_m\) and \(D_{max}\) values for bone homogeneous inserts with a field size of 10×10 cm \((p=0.002)\) (Table 3).

There was significant difference between bone insert and all insert with opposed field beams \((p<0.001)\). However, % accuracy was better with all inserts (2.07) than with bone insert (2.88). This result also confirms the reason for the better accuracy noticed with all insert with 12 beams and bone insert with 6 beams. This shows that the phantom gave better accuracy with inhomogeneous inserts than homogeneous insert (Table 4).

Validation of our locally designed phantom and the standard water phantom showed a 0.3% deviation. This proves that the designed head and neck phantom was good, although there was significant difference in the \(D_m\) value \((p<0.001)\) (Table 5).

Generally, the results measured were within the range of ±5%, as recommended by ICRU,\cite{6} and were consistent with the results of Van Dyk, whose variation was within ±4%, except that for six fields with four inhomogeneous inserts with a field size of 5×5 cm which was higher (4.60%).\cite{26} Results by Mijnheer et al.\cite{23} and Brahme et al.\cite{32} were within 3%–3.5%, whereas those in this study were higher and in the range of 0%–4.6%. Akpochafor et al. used a locally designed pelvic phantom with the same algorithm with a maximum percentage deviation of 4%, against 4.6% which proves to be better than that determined in this study.\cite{31} This deviation could be attributed to different densities of organs within the head and neck region and associated error using small field size.

**Conclusion**

The locally designed phantom showed good accuracy for the 10×10 cm field for different inserts. Deviation was higher with the 5×5 cm for different material media (inhomogeneities). The designed phantom will be suitable in a region like the head where various tissue densities are noticed. The locally designed phantom has proven to be suitable for quality control test in determining the accuracy of the TPS algorithm during radiotherapy. It will most likely be applicable in places in Nigeria where readymade phantoms are not available.

**Disclosures**

**Ethics Committee Approval:** The study was approved by the Local Ethics Committee.

**Peer-review:** Externally peer-reviewed.

**Conflict of Interest:** None declared.

References


