Radiotherapy dose verification on a customised head and neck perspex phantom

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Abstract. IMRT dose planned for head and neck radiotherapy was verified using a customised acrylic head-and-neck phantom. The dosimeters used were calibrated Gafchromic EBT2 film and metal–oxide–semiconductor-field-effect-transistor (MOSFET). Target volumes (TV) and organs-at-risk (OAR) which were previously contoured by an oncologist on selected nasopharynx (NPC) patients were transferred to this phantom by an image fusion procedure. Three radiotherapy plans were done: Plan1 with 7-fields intensity-modulated radiotherapy (IMRT) of prescribed dose 70 Gy using 33 fractions; Plan2 with 7-fields IMRT plan at 70 Gy and 35 fractions; and Plan3 which was a mid-plane-dose (MPD) plan of 66 Gy at 33 fractions. The dose maps were first verified using MapCheck2 by SNC-PatientTM software. The passing rates from gamma analysis were 97.7% (Plan1), 93.1% (Plan2) and 100% (Plan3). Percentage difference between Treatment Planning System (TPS) calculated dose and MOSFET measured dose was comparatively higher than those from EBT2. Calculated dose and EBT2 measured doses showed differences of within the range of ±3% for TV and <±10% for OARs. However MOSFET had differences of within the range of ±6% for TV and within the range of ±10% for OARs between measured and planned doses. An overdose treatment may occur as TPS calculated doses were lower than the measured doses in these plans. This may be due to the effects of leaf leakage, leaf scatter and photon backscatter into the measuring tools (Pawlicki et al., 1999 and Ma et al., 2000). More IMRT plans have to be studied to validate this conclusion. However, the dose measurements were still within the 10% tolerance (AAPM Task Group 119). In conclusion, both Gafchromic EBT2 film and MOSFET are suitable for IMRT radiotherapy dosimetry.

1. Introduction

In vivo dosimetry plays an important role in quality assurance (QA) in radiotherapy especially in advanced radiotherapy techniques like IMRT. Conventional dosimeter such as ionisation chamber (IC), semiconductor detector and thermoluminescence dosimeter (TLD) often fail to meet the requirement to provide high spatial resolution of dose distributions and absolute dose determination at point of interest. Gafchromic EBT2 film provides high spatial resolution of dose distribution which is necessary for IMRT QC whereas MOSFET’s characteristic like easy to use, small size, light weight, instant readout and reducing time for processing. Therefore, MOSFET and Gafchromic EBT2 film were used as clinical dosimeters in this study. The main objective of this study is to verify the exposed radiation dose of TV and OAR for NPC radiotherapy, in conventional MPD and IMRT plan. Dose verification can detect any differences between planned and delivered doses; it is performed on a customised acrylic (Perspex) head and neck phantom using Gafchromic EBT2 film and MOSFET.
1.1. Simulation
In the very beginning for nasopharynx (NPC) radiotherapy, the oncologist will mark the desired treatment area on the patient’s skin by estimation from anatomical structure. With improvement in technology, NPC radiotherapy went from conventional simulation using a simulator named two-dimension (2D) treatment planning to Computed Tomography (CT) simulation. The latter was named three-dimension (3D) treatment planning and now even four-dimension (4D) treatment planning [1].

In radiotherapy planning, it is crucial to have a comfortable positioning for patient for high reproducibility. An immobilisation tool, for example a beam directional shell (BDS), is commonly used in NPC radiotherapy to ensure high reproducibility of treatment.

1.2. Radiotherapy Planning
Radiotherapy planning is the process of determining the best method of treating a TV using high energy radiation. The main purpose of radiotherapy planning is to ensure TV receives a uniform and adequate radiation dose whilst the healthy tissues and OARs are protected.

Lead block or multi-leaf collimators (MLCs) will enhance the radiotherapy plan by shielding the OARs risk and healthy tissues from irradiation. Manual calculation of dosage or complex computerised planning will be the next step of radiotherapy planning.

MPD plan is a parallel opposed field beam configuration [1] used in 2D treatment planning. This field arrangement is suited for treatment of midline structures. Since the human head is symmetrical and nasopharyngeal tumor is assumed to be located along the midline of the clivus bone, NPC can be treated with lateral MPD plan. IMRT is an advanced conformal radiotherapy that utilizes computer optimised inverse treatment planning and computer controlled treatment delivery [2]. It is currently the most favoured choice for head and neck cancer radiotherapy, including NPC. This radiotherapy involves multiple beam angles and segments which have varied or modulated dose intensity. It is able to produce a customised radiation dose intensity to maximize the TV dose while minimizing the dose to adjacent OAR and healthy tissues.

1.3. Dose Verification and Radiotherapy Delivery
After treatment planning, the next procedure is dose verification prior to radiotherapy delivery. Since IMRT has high complexity dose patterns and techniques, quality control (QC) should be done for both equipment operation and delivery of treatment to individual patients [3]. In Cancer Centre Pantai Hospital Penang, for equipment operation, QC was done using MapCheck2 to check the dose map whereas for patient, portal film or electronic portal imaging (EPID) was taken before the start button was pressed. Measurements on phantom where the human anatomy is reproduced are often recommended in addition to in-vivo measurements [4]. Therefore, a series of tests using in-vivo measurement tools like Gafchromic EBT2 Film and MOSFET were performed on the phantom.

Radiotherapy is delivered once the verification in dose and patient positioning passed the requirement. In normal cases, NPC radiotherapy is delivered over a total of 33 - 37 fractions with five fractions per week.

2. Methodology

2.1. Fabrication of Phantom
A set of CT scans for a NPC case which can represent an average patient size was selected from the XiO TPS, Cancer Center Pantai Hospital Penang. The head and neck contours were printed out first in paper at 1 cm thickness in transverse plane from the level vertex of head to chest. The papers were traced onto a 1 cm Acrylic (Perspex) slices according to the slices sequences. Acrylic slabs were cut using electronic hand cutter and polished to make shape smooth. The cut acrylic slices were then stacked together using adhesive double side tape to ensure no air gaps remained in between the slabs. A customised head and neck phantom is formed when all the slices were stacked together (Figure 1).
Figure 1. Customised Perspex head and neck phantom using 1 cm slice of acrylic (Perspex). Both the front and side views are shown.

2.2. Calibration of dosimeters
The dosimeters were irradiated with 6 MV photons at source to surface distance (SSD) of 100 cm and field size used was 10 cm x 10 cm. The dosimeters were placed at 5 cm depth with 10 cm slab of solid water phantom to provide sufficient backscattering. Various parameters such as reproducibility, fading, field size dependence and angular dependence were studied.

2.3. CT simulation
The phantom was set to immobilisation aids like head rest and sponge wedges, and then a BDS was custom-made for this acrylic head and neck phantom. Three lead markers which were visible in CT images were placed on the BDS as setup reference points. The phantom was scanned using Toshiba Aquilllon 64 slices CT scanner then reconstructed to 2 mm slices from vertex of head to chest level (Figure 2). The CT images were exported to CMS XiO TPS through Digitising Imaging and Communication in Medicine (DICOM) system.

2.4. Treatment Planning
According to the International Commission on Radiation Units and Measurements 62 (ICRU 62) [6], the oncologist will contour the target volume with the desired treatment dose. The medical physicist will design a customised radiotherapy planning with appropriate radiation field arrangements.

In this study, the dose verification of three radiotherapy plans planned by XiO TPS; MPD plan and two different seven fields IMRT plans were done on a customised acrylic head and neck phantom.

TV and OARs (brainstem, left eye, right eye, left parotid, right parotid and oral cavity) which were previously contoured by oncologist and medical physicist on the selected NPC patient was transferred to this phantom by image fusion procedure. Two 7 field IMRT plans were planned at gantry angle 0°, 51°, 102°, 153°, 207°, 258° and 309°. The differences of these two IMRT plans were the prescribed dose and fractions. A simple MPD plan using two lateral opposed fields onto the PTV area and with MLCs to shield the OARs and healthy tissues was planned. As a summary, Plan 1 is 7-field IMRT plan with prescribed dose of 70 Gy in 33 fractions; Plan 2 is 7-field IMRT plan with 70 Gy in 35 fractions; and Plan 3 is mid-plane dose plan with 66 Gy in 33 fractions.

2.5. Treatment Delivery and Verification
Then these three plans were optimised, the doses were verified using MapCheck2 as per routine for dose QC at Cancer Center Pantai Hospital Penang. All the fields were set to gantry angle 0° and then exposed to the MapCheck2 to get a dose map. This measured dose map was then compared with the planned dose map by the SNC Patient™ software for all the three plans.

The phantom was properly aligned on the LINAC couch according to the three lead markers on the BDS with setup same as per CT simulation process (Figure 3) aided by electronic portal imaging device (EPID)[7]. Both the Gafchormic EBT2 film pieces and MOSFET were set on the points of interest (POI) for measurements (Figure 4). The three plans were delivered to the phantom and measurements were recorded. The minimum dose, maximum dose, mean dose and point doses for selected TV and OARs by TPS calculation were recorded. In order to validate the comparison in dose
(cGy), the exposed Gafchromic EBT2 films were scanned and the pixel value converted to optical density then to dose (in cGy); MOSFET readings in millivolts (mV) were converted into dose (cGy).

Figure 2. Customised Perspex phantom with immobilisation aids and BDS was scanning by CT scanner (Source: Picture was taken at CT simulation room, Cancer Center Pantai Hospital Penang).

Figure 3. Setup of Perspex phantom on the LINAC couch (Source: Picture taken at LINAC treatment room, Cancer Center Pantai Hospital Penang).

Figure 4. Set up of Gafchromic EBT2 film and MOSFET onto the phantom’s Perspex slice.

3. Results and Discussion

3.1 Calibration of Dosimeters
Accordingly to ISO methodology as described in IAEA TRS-398 dosimetry protocol, the uncertainties of Gafchromic EBT2 Film and MOSFET measurements were derived [5] and given in Table 1. The combined standard uncertainty, \( U(x) \), from source of uncertainties of \( U_a(x) \), \( U_b(x) \), \( U_c(x) \) was calculated by equation 1.

\[
U(x) = \sqrt{(u_a(x))^2 + (u_b(x))^2 + (u_c(x))^2 + \ldots etc.} \quad (1)
\]

The dosimeters Gafchromic EBT2 and MOSFET were first characterized. Gafchromic EBT2 had a 5.05% combined standard uncertainty which were from uncertainties in reproducibility, film darkening effect, field size and angular dependence. MOSFET had 2.94% combined uncertainty from uncertainties like reproducibility, fading effect, field size and angular dependence.

Table 1. Summary of uncertainties and calculated combined standard uncertainty for Gafchromic EBT Film and MOSFET.

| Uncertainty (%)                  | Gafchromic EBT2 Film | MOSFET |
|---------------------------------|----------------------|--------|
| Reproducibility                 | 0.25                 | 1.36   |
| Film Darkening Eff (EBT2 Film) / Fading eff (MOSFET) | 0.02 | 0.64 |
| Field Size Dependence           | 4.73                 | 1.54   |
| Angular Dependence              | 1.76                 | 2.00   |
| Combined standard uncertainty   | 5.05                 | 2.94   |

3.2 Treatment Delivery and Verification
The dose calculated by TPS was first verified by comparing the calculated dose map with the measured dose map from MapCheck2 at DTA of 3 mm and dose difference of 3%. The results are shown in Table 2.
Table 2. Comparison of selected points between TPS calculated doses with Gafchromic EBT2 Film measurements and MOSFET measurements for the three plans.

| Variables | Tool                  | Plan 1 | Plan 2 | Plan 3 |
|-----------|-----------------------|--------|--------|--------|
|           |                        | Medians | % Difference with TPS | Medians | % Difference with TPS | Medians | % Difference with TPS |
| Tumor Volume | TPS                   | 173.49 (1.17) 0.002 | 0.96 | 148.62 (0.40) | 0.002 | 1.99 | 199.49 (0.06) | 0.002 | 1.19 |
|           | EBT2                   | 25.57 (0.36) | - | 149.59 (0.06) | - | - | 211.67 (0.42) | - | - |
|           | MOSFET                 | -        | - | - | - | - | - | - | - |
| Brainstem | TPS                   | 152.42 (0.10) | - | 152.42 (0.06) | - | - | 152.42 (0.10) | - | - |
|           | EBT2                   | 25.57 (0.36) | - | 25.57 (0.36) | - | - | 25.57 (0.36) | - | - |
|           | MOSFET                 | -        | - | - | - | - | - | - | - |
| Oar Concord | TPS                 | 82.43 (0.90) | 0.002 | 82.43 (0.90) | 0.002 | 82.43 (0.90) | 0.002 | 82.43 (0.90) | 0.002 | 82.43 (0.90) | 0.002 |
|           | EBT2                   | 78.64 (1.44) | - | 78.64 (1.44) | - | - | 78.64 (1.44) | - | - |
|           | MOSFET                 | -        | - | - | - | - | - | - | - |
| Non-Tumor | TPS                   | 106.95 (0.46) | - | 71.43 (0.05) | - | - | 155.93 (0.13) | - | - |
|           | EBT2                   | 121.33 (0.29) | - | 65.95 (1.75) | - | - | 164.89 (0.05) | - | - |
|           | MOSFET                 | -        | - | - | - | - | - | - | - |
| Right Parotid | TPS             | 81.64 (0.10) | - | 71.43 (0.05) | - | - | 155.93 (0.13) | - | - |
|           | EBT2                   | 78.64 (1.44) | - | 78.64 (1.44) | - | - | 78.64 (1.44) | - | - |
|           | MOSFET                 | -        | - | - | - | - | - | - | - |
| Left Parotid | TPS               | 81.64 (0.10) | 0.002 | 81.64 (0.10) | 0.002 | 81.64 (0.10) | 0.002 | 81.64 (0.10) | 0.002 | 81.64 (0.10) | 0.002 |
|           | EBT2                   | 78.64 (1.44) | - | 78.64 (1.44) | - | - | 78.64 (1.44) | - | - |
|           | MOSFET                 | -        | - | - | - | - | - | - | - |
| Right Eye | TPS                   | 57.13 (0.11) | 0.002 | 57.13 (0.11) | 0.002 | 57.13 (0.11) | 0.002 | 57.13 (0.11) | 0.002 | 57.13 (0.11) | 0.002 |
|           | EBT2                   | 22.02 (0.25) | - | 22.02 (0.25) | - | - | 22.02 (0.25) | - | - |
|           | MOSFET                 | -        | - | - | - | - | - | - | - |
| Left Eye | TPS                   | 24.81 (0.52) | 0.002 | 24.81 (0.52) | 0.002 | 24.81 (0.52) | 0.002 | 24.81 (0.52) | 0.002 | 24.81 (0.52) | 0.002 |
|           | EBT2                   | 22.02 (0.25) | - | 22.02 (0.25) | - | - | 22.02 (0.25) | - | - |
|           | MOSFET                 | -        | - | - | - | - | - | - | - |

The measured dose maps from all the three radiotherapy plans were in the 10% tolerance as accepted in the protocol of Cancer Center Pantai Hospital Penang. The passing rates from gamma analysis were 97.7 %, 93.1 % and 100 % for Plan 1, Plan 2 and Plan 3 respectively. This shows that the calculated dose by TPS and measured map were in agreement. Hence, the calculated dose from TPS can be used to compare the measured dose by the dosimetry tools.

By Kruskal-Wallis test and Mann-Whitney test (the post hoc analysis), the medians of three dosimeters (TPS, MOSFET, EBT2 film) are significantly different (p<0.05). On the whole a percentage difference of less than ± 3 % were found between TPS calculated dose and the Gafchromic EBT2 film measured dose distribution for TV. Higher percentage differences for OARs of less than ± 10 % were found. Plan 1 and Plan 2 are IMRT plans; IMRT plans have high complexity and sharp dose gradients between TV and spared healthy tissues. The percentage difference is high for some measured POI, but it is still within the range between the minimum and maximum dose. However, Gafchromic EBT2 film showed a lower percentage difference of less than ± 6 % in Plan 3 which is the MPD plan. MPD plan has a more uniform dose in the region of treatment, where the dose has a nice square dose contour or a slightly hour glass shape of isodose lines [1]. Since the dose distribution for MPD plan is comparatively uniform, the measured doses agreed with the calculated dose by TPS.

On the other hand, the percentage difference between the calculated dose by TPS and the measured dose by MOSFET was comparatively higher than that of Gafchromic EBT2 film. A highest difference of 21.78 cGy occurred in brainstem in Plan 2. This may be due to MOSFET measuring only at a point whereas Gafchromic EBT2 film measured over a small area and average dose is over this small area.

In conclusion the TPS calculated dose and the MOSFET measured dose showed a percentage difference of less than ± 6 % for TV and ± 10 % for the OARs. Brainstem is the organ which is just next to TV. Although this is in a high dose gradient, the brainstem is under the tolerance dose. Hence brainstem showed the highest percentage differences of 9.98 % and 9.62 % in both IMRT plans.

The point of measurement was difficult to define as the point was often located in a steep gradient dose in IMRT treatment [8]. Therefore, the uncertainty in positioning of the detector on the phantom would introduce the dose difference in the measurement. The misplacement error should be eliminated to ensure the measured dose occurs at the same location at each measurement [7]. Therefore, verification process using portal imaging is highly recommended to reduce misplacement error.
Nevertheless, the TPS calculated dose was normally lower than the measured dose by Gafchromic EBT2 film and MOSFET. This may be due to the effects of leaf leakage, leaf scatter and photon backscatter into the measuring tools [8-13].

4. Conclusion
An overdose treatment may occur to patient as the TPS calculated doses were lower than the measured doses either by Gafchromic EBT2 film or MOSFET for the IMRT plans. More IMRT plans have to be studied to validate this conclusion. However, the dose measurements were still within the 10% tolerance which is the acceptance protocol of Cancer Center Pantai Hospital Penang (AAPM Task Group 119) [14]. In conclusion, both Gafchromic EBT2 film and MOSFET are suitable for use in radiotherapy dosimetry.

5. References
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