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Research Article

Experimental Determination of Scattered Radiation to Risk Organs in the Treatment of Head Carcinomas Using an Anthropomorphic Phantom

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Abstract

Prime Phantom: An Instrument That Improves Radiotherapy Practice, Ensuring High-Quality and Safe Treatments. Prime Phantom can evaluate the entire treatment chain, addressing both clinical and technical aspects. Comprehensive evaluation of the entire treatment chain, from CT to irradiation. Dosimetry and geometric precision using point, 2D, and 3D dosimeters. In this study, we aimed to evaluate the radiation dose measured with a patient-specific gel phantom that combines Three-Dimensional (3D) printing and polymeric gel. The dose with which the patient is irradiated is applied as in a real setting to assess the utility of testing the gel dose and phantom produced in a real treatment environment. In the current research, we performed 3D dose evaluations by arranging an ionization chamber inside the phantom, irradiating it with a therapeutic dose to a phantom covered with a polymeric gel. Quality Assurance (QA) measurements specific to the patient's dosimetry (DQA) are always performed to verify that the irradiation is applied accurately based on the patient's treatment plan to ensure the precision of such treatment. A patient's treatment plan follows a Three-Dimensional (3D) dose distribution since it is implemented in three dimensions.

Keywords: X-rays, Phantom, Out-of-field dose, Lead shields

Introduction

Carcinomas represent most malignant tumors of the skin. According to their main histological forms, spino and baso-cellular are the most common ones. Moderate skin carcinomas are curable by radiological methods X-rays beams. From medical and aesthetic reasons, radiotherapy is the first choice in the treatment of epitheliomas located in the face and hands. In radiotherapy, the precise determination of the dose in the target volumes and in the risk, organs represent very important aspects for ensuring an optimal treatment plan [1]. Doses in the organs at risk are evaluated according to the international regulations QUANTEC [2]. Compliance with dose constraints reduces the early and late effects of radiation. The main concern with off-field radiation is that even relatively small off-target doses have the potential to induce secondary cancer (stochastic effects) and can also cause other problems such as cataracts. Radiation protection must ensure an appropriate standard of protection without over-limiting the medical benefits. Many clinical cases use high atomic number materials as shielding to reduce the photon dose to the underlying healthy tissues.

The complexity of contemporary radiotherapy requires a new approach to quality assurance. Until now, no universally accepted technique has been available for evaluating global dosimetric performance. For this study, an anthropomorphic head phantom, resembling the real anatomies of patients, was used. The phantom was 3D printed based on a CT scan of the patient and is commercially available. Studies have evaluated the appropriate use of 3D printed head phantoms with bone-mimicking materials for specific patient plan verification procedures, demonstrating excellent agreement with the actual patient. Gel dosimetry allows for the evaluation of 3D dose distributions. The empty phantom with internal anatomical bone structures can be filled with water and has an insertion to support an ionization chamber for point-dose measurement. For more accurate dose evaluation, a phantom should be fabricated in the same shape as the human body, rather than using a uniform shape. Dose distribution can be evaluated using a 3D printed phantom. A patient-specific phantom can be fabricated using precise imaging techniques such as Magnetic Resonance Imaging (MRI), Computed Tomography (CT), and Positron Emission Tomography/Computed Tomography (PET/CT) images, with materials that have a density similar to that of the human body, taking into account the characteristics of each patient [3].

RTSAFE can create a patient-specific head phantom that reacts to radiation exactly as human tissue does. The RTSAFE Prime anthropomorphic head phantom was used to verify the accuracy of dose measurements for quality assurance. The unique features of the Prime phantom, combined with the option for point, 2D, and 3D dosimetry, allow for multi-level treatment accuracy evaluation, from imaging to planning and dose delivery. The Prime phantom broadens the quality assurance spectrum through an integrated solution. It provides comprehensive dosimetry in a real human anatomy phantom for end-to-end evaluation of advanced radiotherapy applications. The Prime phantom allows for 3D gel dosimetry measurements to assess spatial accuracy in complex treatments [4].

Experimental Setup

Materials

For this study, we used a head phantom that was manufactured by RTSAFE (Athens, Greece), using the CT images of the patient to produce a customized phantom for the patient. The phantom produced by RTSAFE uses a Colour Jet printing technique from the Project 360 3D Printer (3D Systems, Morrisville, NC, USA). After spraying the liquefied material layer by layer, the material is solidified using high-performance Ultraviolet (UV) light to create the phantom's shape. Each printed phantom layer is 0.1mm thick, and the phantom can be produced based on the patient's anatomy using CT images. The 3D printed head phantom includes skin and bone structures, and the soft tissue is filled with a polymeric gel, which is a water-equivalent material allowing for 3D dose evaluation [4].

A 2 Gy radiation dose was irradiated through the treatment plan using 3D printing, allowing us to create phantoms with variable density for patient-specific Dosimetry Quality Assurance (DQA), to develop a customized body phantom for the patient in the future, and to perform patient-specific dosimetry.

Here, patient-specific DQA is performed using an ionization chamber and a phantom composed of a single material in which the detector can be inserted. The dose for each patient is evaluated using a single-material phantom made with a water-equivalent material since the phantom cannot account for the density and shape of each patient's tissue. There are only a limited number of studies that have focused on accurately verifying a high-precision radiation treatment plan, as patient-specific DQA is limited to converting a 3D dose distribution into a 1D and 2D dose distribution and performing a comparison.

The XSTRAHL 200 treatment system provides both superficial and semi-deep radiotherapy, offering the flexibility to provide palliative care by treating soft tissues and bone metastases, while simultaneously treating a wide range of superficial skin cancers such as basal cell carcinoma and squamous cell carcinoma, as well as benign dermatological conditions and hyper proliferative diseases. The XSTRAHL 200 X-ray system offers both superficial and deep treatments, combining the capabilities of X-ray systems with high-voltage technology with the traditional ease of use of superficial radiotherapy. XSTRAHL 200, along with the Concerto treatment consoles, ensures a turnkey workflow to develop and deliver superficial treatments. All treatment aspects are planned and recorded, including each treatment field with the administered dose. The integrated physics console simplifies daily workflows. The calibration configuration of the XSTRAHL 200 for each applicator is driven by a separate physics console, ensuring that critical machine data is secure [5]. The access of the physician and therapist is limited to the planning and delivery of treatments for patients, reducing the complexity of daily workflows. Applicators advanced precision of adjustments by full transparent, shielded applicator body and transparent calotte with centering cross. All applicators are distinctive coded and could be assigned unique to one or more half-value-layers. The applicators are available with focus to skin distance 50 cm with rectangular shapes (Figure 1).

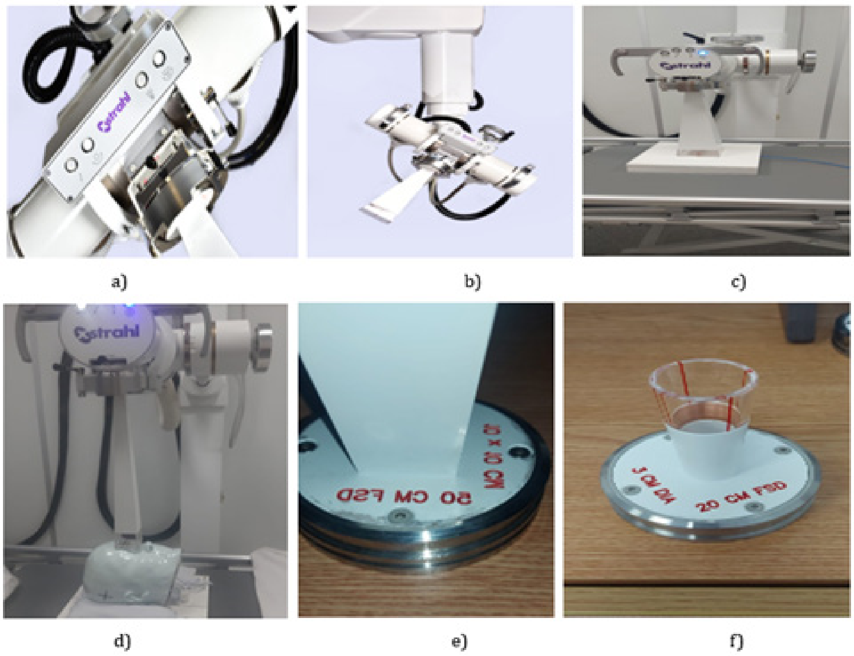

Figure 1: (a) and (b) the mobility of the radiotherapy instalation (c) the placement of ion chamber in plexiglass phantom; (d) the positioning on the RTSAFE phantom; (e) and (f) applicators with different Focus and Skin Distances (FSD) and various square and circular shapes.

Radiation doses have been measured by a Semiflex cylindrical ionization chamber connected a PTW electrometer UNIDOS E 10008, commonly used in clinical dosimetry [6].

Working Procedure

A radiation dose of 2 Gy was delivered via the treatment plan. Treatment plans were made under normal treatment conditions and under protection conditions using Pb sheets. The scattered radiation was measured with an ionization chamber at multiple points inside the phantom and at different depths. Parameters (kV, mA, applicators) were modified to provide a better evaluation of dose distribution under various treatment conditions. The measurements were carried out at same combinations of energy (kV, mA) and filters, for different sizes of the applicator (field size and skin-source distance), protected by thick lead screens different (2mm and 4mm sheets) using the ionization chamber. The study was carried out for the prescribed dose of 2 Gy, in a 3D printed head phantom. Many configurations were measured, for two different applicators, at various combinations of kV, mA and filters, in the beam and outside the central axis of the beam, with protection screens of lead of different thicknesses.

The recording was made by cylindrical ionization chamber and electrometer PTW. Placing detectors at designated locations also allows for dose measurements at the most dosimetrically demanding areas of the brain and the most critical clinical cases.

The experiment reported in the present paper follows the sequence:

a) determination of irradiation parameters (voltage, intensity, applicators, etc.);

b) measurement of dose flow with the ionization chamber calibrated under air kerma conditions;

c) evaluation of attenuation and scattering of the filter lead medium by using measurement results.

These steps have been followed for each new irradiation configuration. A change even in a single parameter can strongly affect the deposition of the actual dose on the skin, especially involving low-energy X-rays.

RTSAFE offers dosimetry services which incorporate phantoms built from real patient anatomical data by combining proven expertise in medical physics with highly accurate 3D printing technology. Point, 2D or 3D dosimetry can be implemented using these dosimetry phantoms. Planning CT scanning, Treatment Planning, Set-up/Immobilization, Image Guidance and Treatment delivery are applied to the RTSAFE phantoms as if they are real living patients.

This approach results in a true End-to-End QA testing that incorporates all links of the treatment chain.

The patient concerns personalized (i.e. patient-specific) Radiotherapy Treatment Verification and Quality Assurance (Figure 2).

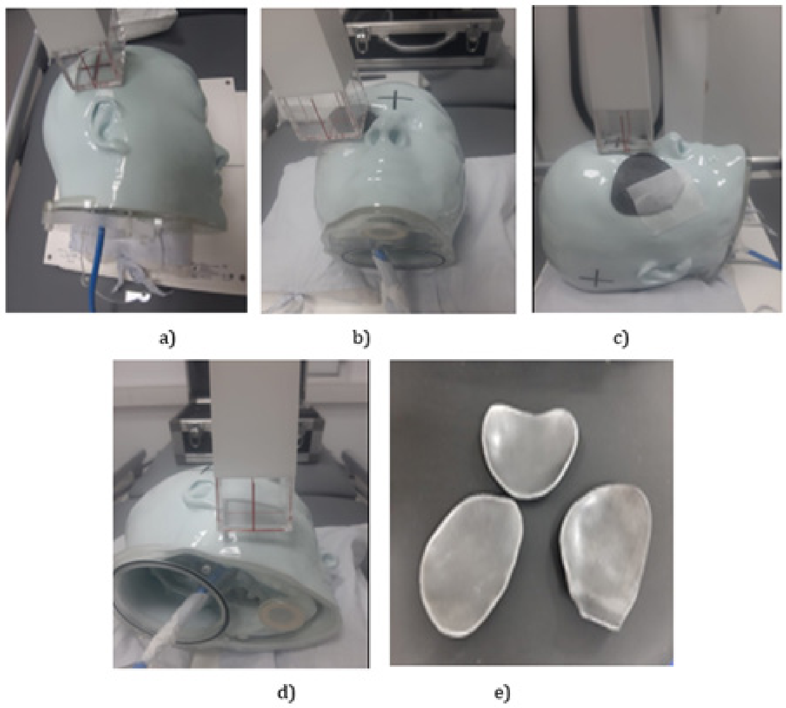

Figure 2: (a, b, c, d) the experimental setup with the ionization chamber positioned inside the phantom and the applicators placed in different positions, as well as lead foils placed over the eye;(e) 2mm thick lead foils used for eye shielding can be observed.

Results

In tables 1-3 are given the experimental results of our measurement. For eye dose determination we have used the applicator 4x4cm (the applicator has square shape with 4cm length). The parameters of irradiation were 200kV and 10mA, with filter by 1mm Cu. When the applicator was positioned above the lead foils covering the eye, the measured dose was different. The presence of Pb sheet determined the decrease of doses value; for eye dose determination, with 2 mm Pb, the dose value was 9.75mGy and for 4mm Pb, the dose value was 8.82mGy Table 1. The distance was measured from applicator's external limit to the position of ion chamber; the depth represents the distance from skin surface to the point where ion chamber is situated, in central axis of beam (Table 1-3).

Table 1: EYE dose Applicator 4x4 (50cm) 200kV / 10mA / 1Cu.

Field	Distance (cm)	Depth (cm)	Dose (Read on the Dosimeter (mGy)	Pb Sheet (mm)
Pyramid	3	2	23.91	0
Preauricular	2	2	25,52	0
Pyramid	2	2	18,06	2
	2	2	18,33	4
Eye	0	0	8,82	4
	0	0	9,75	2

Table 2: BRAIN dose Applicator 6x6 (50cm) 200kV / 10mA / 1Cu.

Field	Distance (cm)	Depth (cm)	Dose (Read on the Dosimeter (mGy)	Pb Sheet (mm)
Temporal	0	5	748	0

Table 3: BRAIN dose Applicator 4x4 (50cm) 200kV / 10mA / 1Cu.

Field	Distance (cm)	Depth (cm)	Dose (Read on the Dosimeter (mGy)	Pb Sheet (mm)
Front	0	10,5	554,4	0
Temporal	0	5	690	0

In Table 1, the ionization chamber was positioned at the level of the eye, at a depth of 2 cm. The applicator was placed in various positions nasal pyramid and preauricular at a distance of 3cm from the chamber position, with and without lead Pb. Also, for the same applicator and the same parameters (voltage, current, and Cu filter), the dose measured by the ionization chamber depended on the thickness of the lead foils. At a greater distance from the applicator, the recorded dose was higher.

In Tables 2 and 3, the ionization chamber was placed inside the phantom, at distances of 5cm and 10.5cm from the applicator position, without lead sheets. In the temporal position, the dose measured by the ionization chamber with the square-base applicator was lower.

The results showed the sensitivity to the type of applicators and the kV values to the geometry of the lead filter thickness and its position of the dose, it contains only a very small, insignificant percentage, passes in to the eyeball.

Conclusion

The 3D-printed head phantom has advantages such as comparing doses between patient prescriptions, personalized Quality Assurance (QA), precision in phantom production, and various application possibilities. Comparative analysis produced better results by validating difficult-to-treat areas through QA using a personalized 3D printing phantom. These results indicate that a personalized phantom can be manufactured not only for the head but also for other parts of the body. It is expected that this study can be applied to precise patient-specific dosimetry in high-energy photon radiation therapy, as well as in particle radiation therapy.

RTSAFE is a medical technology company that has developed a unique approach to quality assurance, significantly improving the safety and accuracy of radiotherapy for cancer and other medical conditions. Our vision is to help create a world where every radiotherapy intervention is tested on a personalized phantom before the real patient, thus enhancing the safety and efficacy of the treatment. We combine proven expertise in medical physics with high-precision 3D printing technology to create pseudo-in-vivo dosimetry phantoms for commissioning, benchmarking, and patient-specific QA applications in SRS, IMRT, VMAT, and SBRT [7]. The precise anatomical models allow healthcare professionals to plan more accurate treatments for each individual patient and help the radiotherapy technology industry adjust its products. The result is a more efficient individualized therapy and a reduced risk for the patient.

Each newly emerged situation that is studied will definitely lead to an improvement in knowledge and to the increase in safety and progress, which will contribute to increase the general survival and to an improvement in the quality of life [8]. Never the less, the cancer treatment is multimodal, with a management requiring a multidisciplinary team, and a difference regarding the staging and location of the primary neoplasia [9] and each case must be approached individually, taking into account the various particular aspects of each patient [8].

Conflict of Interest

None.

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None.

References

1. *https://www.accessdata.fda.gov/cdrh_docs/pdf18/K180697.pdf*
2. *https://pubmed.ncbi.nlm.nih.gov*
3. Yona Choi, Kook Jin Chun, Eun San Kim, Young Jae Jang, Ji Ae Park, et al. (2021) Dosimetric Study Using Patient-Specific Three-Dimensional-Printed Head Phantom with Polymer Gel in Radiation Therapy. Prog Med Phys 32(4): 99-106.
4. *https://rt-safe.com/prime*
5. *https://xstrahl.com/xstrahl-200*
6. *https://www.ptwdosimetry.com*
7. *https://rocketreach.co/rtsafe-profile_b477ad21fc5cbd6f*
8. Rahnea Nita RA, Stoian AR, Anghel RM, Rebegea LF, Ciuhu AN, et al. (2023) The Efficacy of Immunotherapy in Long-Term Survival in Non-Small Cell Lung Cancer (NSCLC) Associated with the Syndrome of Inappropriate Antidiuretic Hormone Secretion (SIADH). Life (Basel) 13(6): 1279.
9. Rebegea LF, Firescu D, Anghel RM, Gales L, Ilie AM, et al. (2021) Clinical, histological and therapeutical aspects in the management of uterine and extrauterine stromal sarcomas: Case reports. Exp Ther Med 22(6): 1456.