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FABRICATION OF A FEMALE PELVIC PHANTOM FOR DOSIMETRIC VERIFICATION OF BRACHYTHERAPY TREATMENT OF CARCINOMA CERVIX

Medical Physics

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ABSTRACT

An accurate way to do radiation dose assessment is with the help of realistic phantoms. For fabrication of the phantom various anatomical structures were delineated on CT images. The electron density of the materials chosen for fabrication was based on HU to electron density calibrations. The CT numbers of the phantom materials and those of the delineated regions on the patient CT were sampled using the Eclipse planning system and indicates agreement. The doses measured with the TLDs were compared with TPS calculated dose in different locations in the phantom like point A, bladder, rectum, left and right femoral head for ICBT treatment planning. The fabricated phantom is a representative female pelvis, realistic in density, size and anatomy and suitable for the evaluation of cervix cancer brachytherapy treatments. The dosimetric measurements confirm the suitability of the fabricated phantom for the verification of dose delivery in brachytherapy of carcinoma cervix.

KEYWORDS

Brachytherapy, Dosimetry, Anthropomorphic phantom

INTRODUCTION

Achievement of higher tumor control probability with reduced treatment morbidity is the ultimate goal of radiotherapy. This goal recognizes that it is not enough to destroy tumor cells and prolong the life of a patient, but the life must be of high quality. An intensive dosimetry is necessary during the implementation of the technique and treatment verification processes. This can be achieved efficiently when a well-designed phantom is available. However, none of the commercially available phantoms simultaneously satisfy all of the dosimetry requirements. Rather, commercial phantoms entail restrictions in measuring the doses and the dose distributions that are specific to individual patient treatment conditions (*Shrotriya et al., 2018)*. Hence these attempt to fabricate an anthropomorphic heterogeneous female pelvic phantom which can be used for dose verification of intra-cavitary brachytherapy.

MATERIALS AND METHODS

Design Criteria for Anthropomorphic Pelvis Phantom

The key design criteria to be met by the phantom were suitability for evaluation of cervix treatments, representative of a median-sized patient in the treatment position, anatomically accurate in terms of geometry, nontoxic materials which will maintain structural integrity, physical and electronic densities to be approximately radiologically equivalent to real tissue, organs to be visually distinguishable for treatment planning, able to accommodate a variety of dosimeters in clinically relevant locations, able to be rapidly assembled and disassembled, demonstrate reproducible assembly and overall weight suitable for manual handling (Harrison et al., 2011).

Material Selection for Phantom Design

Patient tissues were allocated to three distinct groups: bone, organ and tissue. As the exact chemical composition for the materials was protected by industrial confidentiality, material testing was limited to relative testing against water using CT (ICRU Report 44, 1989). This allowed for determination of their attenuation using the corresponding Hounsfield unit (HU) and the linear attenuation coefficient for water measured at the corresponding photon energy (Thomas S J, 1999). CT scanning was replicated as per the protocols used for the patient images. The electron density of the materials chosen for fabrication was based on calibrated HU to electron density.

Identification of Anatomy and Measurement Points Based on Patient CT Scan

The external outline, target volume, femoral heads, bladder and rectum were delineated by a radiation oncologist using the Eclipse planning system on computed tomography (CT) scan of the patient. Delineated structures and external contour were altered or smoothed in shapes as required for milling (Followill et al., 2007, Moore et al., 2006).

Fabrication of Phantom

The phantom design data for the organs, bone and external contour was separated according to each transverse phantom slice. Each organ and bone structure for each individual slice was milled using a Pinnacle milling machine (EXCEL machine tools, Exhall, England).

A mould was created using the external contour for the organs and was accurately positioned with respect to the mould. Liquid material was poured into the moulds and allowed to cure, forming a solid material with close contact to the structures.

After the organs had solidified, recesses were drilled and labelled to meet the design specification for the TLD measurement points. The 3D imaging facilitated definition of the desired positions for thermo luminescence dosimeters (TLD rods). The TLD positions were located at points of clinical interest, these being known disease recurrence sites, within critical organs or near structure junctions. Positions in the bladder and rectum allow assessment of dose within these normal structures. Where spatially allowable, multiple TLD points were located at each measurement point to improve measurement statistics (Paliwal et al. 1998, Ebert et al., 2011, Healy et al., 2011)

An applicator holder was made from a Perspex cylinder with provisions to place TLDs and different intra cavitary brachytherapy applicators with positional reproducibility during multiple treatment fractions. The applicator holder can be filled with water to achieve the desired tissue equivalence.

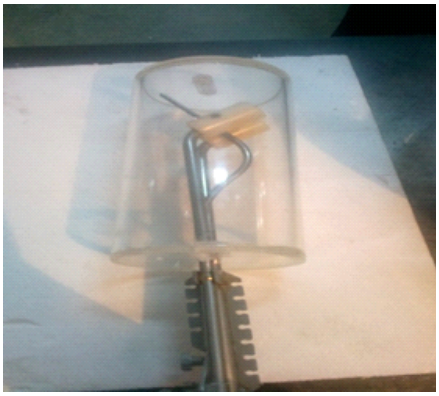

Figure 1: Brachytherapy applicator holder

A slab phantom design deemed appropriate to minimize air gaps between the slices and allow for rapid assembly and disassembly. The phantom slices were determined along transverse planes. To facilitate a

high level of reproducibility, the phantom design incorporated two positioning "rods" passing through each slice.

RESULTS

Physical Properties

The fabricated phantom was simple to assemble with reproducibility using the positioning rods. The dimensions and relative location of anatomy matched the design. The fully assembled phantom weighed 10 kg. The CT numbers of the phantom materials and those of the delineated regions on the CT of the patient used to model the phantom were sampled using the Eclipse planning system and tabulated in table 1. The values indicate the agreement between the phantom and patient CT numbers within the tolerances (ranges of maximum and minimum values) of the sampling.

Table 1: Comparative CT no.s of the phantom materials and those of the representative patient

Contoured anatomical region	Phantom CT number	Patient CT number
Tissue	130(112-148)	110(98-126)
Organ(bladder/ rectum)	100(81-113)	109(102-115)
Bone(inside femoral head)	350(330-384)	369(321-389)

ICBT Treatment Planning and Measurement, Dosimetric Evaluation Using the Fabricated Phantom.

The fabricated phantom with the HDR ICBT applicator insert was CT scanned and a brachytherapy plan was generated using Brachyvision planning system. The plan was executed on a Gammamed plus HDR machine and the variation between planned and measured doses at clinically important points were evaluated using TLD roads. The measurement setup is shown in figure 2.

The percentage deviation for all measurement points was within 3% and maximum value of percentage deviation observed was 2.38% for the right femoral head position.

Figure 2: phantom setup for ICBT

DISCUSSION

Assessment of Physical Properties of Fabricated Phantom

The phantom was inspected following fabrication to ensure the physical dimensions of the phantom constituents and overall dimensions matched the design, the weight was suitable for handling and travelling, the dosimeter locations were accurate and that the phantom was robust on re assembly. To assess approximate CT number matching, the phantom was positioned in the CT scanner (Philips MX-16) and helical scans taken (tube voltage 120 kVp; tube current 230 mA; 512×512 pixels; 2 mm slice intervals) and the images were imported into the Eclips planning system. The CT numbers were sampled, using the CT no. / HU software tool within the planning system, for the phantom materials and those of the delineated regions on the CT of the patient used to model the phantom. The median CT values were compared and tolerances were defined according to maximum and minimum values of the sampling.

ICBT Treatment Planning and Measurement, Dosimetric Evaluation Using the Fabricated Phantom

For the cervix brachytherapy treatment dose was calculated by using CT scan images produced in a simulation of patients who were subjected to a tandem and ovoid in intra cavitary brachytherapy for carcinoma of the uterine cervix. Point A was configured 2 cm away from both the anterior and lateral side of the cervical os (AAPM Report 51, 1996). Four reference points were configured to bladder and rectum to determine the rectal and bladder doses in a simulation treatment. Three measurement points each for left and right femoral heads also was determined to evaluate the normal structure doses (Candela et al., 2013, Nath et al., 1995). Regional lymph node positions on both left and right sides were also located. A treatment planning system (Brachyvision) was used for dose calculation.

CONCLUSION

The fabricated phantom is a representative female pelvis, which ensured the phantom was realistic in size and anatomy and suitable for the evaluation of cervix cancer brachytherapy treatments. Materials to fabricate the phantom were chosen to avoid toxic or degradable properties and to be strong enough to maintain structural integrity. The materials chosen approximate tissue, organ and bone densities and allow for distinguishable structures in treatment planning. PMMA was selected for tissue, wax for bladder and rectum and Du Pont Delrin acetal homo polymer resin for femoral heads. The fabricated phantom can accommodate TLDs for measurements. The phantom can be rapidly assembled and disassembled reproducibly with the help of the positioning rods. The weight and size of the phantom makes it suitable for manual handling and transport. It is a cost effective phantom when compared to commercial phantoms. The dosimetric measurements show that the fabricated phantom can be used for the verification of dose delivery in intra cavitary brachytherapy applications.

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